NASA Technical Memorandum 88380

NASA INFORMATION SCIENCES AND HUMAN FACTORS PROGRAM

ANNUAL REPORT, 1985

JANUARY 1986

Automation and Robotics

Communications Systems

Computer Sciences

Controls and Guidance-Aeronautics

Controls and Guidance-Space

Data Systems

Human Factors-Space

Sensor Technology

NASA Technical Memorandum 88380

NASA INFORMATION SCIENCES AND HUMAN FACTORS PROGRAM

ANNUAL REPORT, 1985

PREPARED BY

NASA Office of Aeronautics and
Space Technology

Information Sciences and
Human Factors Division

INTRODUCTION

The Information Sciences and Human Factors (IS&HF) Division is one of five divisions that comprise the Office of Aeronautics and Space Technology (OAST). This division sponsors research in both aeronautical and space technology; the Annual Report documents the most significant program accomplishments during the past year. Each year, the Annual Report is prepared to serve as the single mechanism for coordinating NASA activities with industry and industrial IR&D managers. This document is also intended to communicate significant technical accomplishments to NASA technologists and project engineers and to other government agencies and academia.

The IS&HF Program consists of seven major elements: Automation and Robotics, Computer Sciences, Communications Systems, Controls and Guidance, Data Systems, Human Factors, and Sensor Technology. Accomplishments are presented in all seven categories; Controls and Guidance and Human actors are shown in two sections, Space and Aeronautics. The program technical objectives, sub-elements, related NASA programs and potential applications are included in the appropriate section. Program funding for fiscal year 1986 is shown below.

Element	Aero ($M)	Space ($M)	Total R&D ($M)
Automation and Robotics		10.2	10.2
Communications Systems		7.1	7.1
Computer Science	22.2	4.4	26.6
Controls and Guidance	28.4	6.6	35.0
Data Systems		7.1	7.1
Human Factors	8.3	2.3	10.6
Sensor Technology		6.0	6.0

To aid in the communication of program efforts, the names and phone numbers of Headquarters' program managers are included in this report along with the names and phone numbers of the key Center technologists who conducted or managed the significant technology activities.

DIVISION DIRECTOR: Lee Holcomb
(202) 453-2747

ACTING DEPUTY DIRECTOR: Carol Roberts
(202) 453-2745

NASA DIRECTORY

Center	Symbol
Ames Research Center Moffett Field, CA 94035	ARC
Ames Research Center Dryden Flight Research Facility PO Box 273 Edwards, CA 93523	DFRF
Goddard Space Flight Center Greenbelt, MD 20771	GSFC
Headquarters NASA/OAST/RC Washington, DC 20546	HQ
Jet Propulsion Laboratory 4800 Oak Grove Drive Pasadena, CA 91109	JPL
Lyndon B. Johnson Space Center Houston, TX 77058	JSC
John F. Kennedy Space Center Kennedy Space Center, FL 32899	KSC
Langley Research Center Hampton, VA 23665	LaRC
Lewis Research Center 21000 Brookpark Road Cleveland, OH 44135	LeRC

TABLE OF CONTENTS

	PAGE
INTRODUCTION	iii
NASA DIRECTORY	iv
AUTOMATION AND ROBOTICS	1
Off-Line Demonstration of DEVISER on Voyager-Uranus Sequence Generation	2
PLAN-IT: An Expert System Schedule Planner	4
Automated Subsystem Management	6
Artificial Intelligence Research Group: Expert Systems Programs	8
Machine Vision	10
Roles of Human and Robotic Capability in Space	12
Telerobotics Technology Integration and Demonstration	14
Force/Torque Display and Control for Telerobotic Systems	16
Automation Performance Measures	18
Manipulator Control Mechanization Development	20
Force-Reflecting Hand Trigger Development	22
Human Stereo Vision Research for Space Teleoperation	24
Neuromuscular Factors Research for Force-Reflecting Manual Control in Zero-G Teleoperation	26
COMMUNICATIONS SYSTEMS	29
Hoop Column Deployable Antenna System	30
The Development of an Electromagnetic Analysis Method for Mesh Deployable Antennas	32
Near Field Phase Measurements for Improving the Surface Accuracy of a Large Deployable Reflector Antenna	34
8-Beam Overlapping Cluster Feed for Mobile Satellite Applications	36
20 GHz MMIC Transmit Module	38
Monolithic 30 GHz 5 Bit Phase Shifter	40
60 GHz TWT for Intersatellite Links	42
Efficient Solid State Power Amplifier Technology	44
Surface Acoustic Wave Resonator Oscillator (SAWRO)	46
Digital Filter Processor Chip	48
X-Band Dielectric Resonator Oscillator (DRO)	50
Laser Communications	52
COMPUTER SCIENCES	55
Massively Parallel Processor (MPP)	56
Software Management Environment	58
Software Life Cycle Model	60
Development of a Theoretical Basis for the Assessment of Software Redundancy	62
RIACS: Research Institute for Advanced Computer Science	64
CASIS: Center for Aeronautics and Space Information Sciences	66
Programmable Mask Technology	68

TABLE OF CONTENTS (CONT.)

	PAGE
COMPUTER SCIENCES (Cont.)	
Optical Information Processing	70
Hyperspectral Analysis	72
ARC Concurrent Processing Research	74
Intelligent Data Management	76
Distributed Access View Integrated Database (DAVID) System	78
CONTROLS AND GUIDANCE - AERONAUTICS	81
Allowable Time Delays in Large Transport Responses	82
Optimal Control in Wind Shear	84
Full-Color Electroluminescent Flat-Panel Display	86
Verification Technology for Digital Flight Control Systems	88
The SURE Reliability Analysis Program	90
Digital System Lightning Upset Assessment	92
Total Energy Control System	94
Applications of State Estimation in Aircraft Flight-Data Analysis	96
Beacon Landing System (BLS) and Portable Tactical Approach Guidance (PTAG)	98
Rotorcraft Systems Integration Simulator Upgrade to Vertical Motion Simulator	100
Rotorcraft Air Combat Simulation	102
Integrated Airframe/Propulsion Control System Architectures	104
Advanced Automated Guidance Laws for High-Performance Aircraft	106
CONTROLS AND GUIDANCE - SPACE	109
Control of Flexible Structures (COFS) Flight Experiment Program	110
Spacecraft Control Laboratory Experiment	112
Ground Facility for Large Space Structure Control Verification (GS/LSSCV) - Test Configuration 1	114
Ground Facility for Large Space Structure Control Verification (GS/LSSCV) - Test Configuration 2	116
System Identification	118
Nonlinear Simulation and Modeling	120
Unified Control Structure Modeling and Design	122
Spatial, High Accuracy, Position-Encoding Sensor (SHAPES)	124
Automated Adaptive Control Subsystem	126
Advanced Precision Pointing Technology	128
Construction/Docking Technology	130
AOTV GN&C Research	132
Guidance, Navigation, and Control for Future Aeromaneuvering Vehicles	134
Fiber Optic Rotation Sensor (FORS)	136
Advanced Autopilot for Spacecraft (AAPS)	138
STS Guidance and Control	140

TABLE OF CONTENTS (CONT.)

	PAGE
DATA SYSTEMS	143
Advanced Distributed System Networks	144
On-Board High Speed Adaptive Processor	146
Fiber Optic Data System	148
Fiber Optics Transceiver	150
VHSIC Processor Technology for Advanced Computing	152
VHSIC Technology Insertion	154
Advanced Information Processing System (AIPS)	156
Spaceflight Tera (10^{12}) Bit Optical Disk Buffer	158
Advanced Digital SAR Processor (ADSP)	160
MAX - A High Speed General Purpose Multicompiler for Space Applications	162
Advanced General Purpose Computer	164
Spaceborne VHSIC Symbolic Processor	166
HUMAN FACTORS - AERONAUTICS	169
Aircraft Automation: Field Studies and Guidelines	170
Intelligent Cockpits: Pilot-Matched CDU Organization	172
Artificial Intelligence Concepts for Flight Crew Aiding	174
The Causes and Effects of Runway Transgressions	176
Pilot Performance Factors in Short-Haul Flight Operations: A Field Study	178
International Long-Haul Layover Sleep Study	180
Objective Assessment of Pilot Performance	182
Development of Workload and Performance Assessment Methods	184
Workload Prediction	186
Brainwave Measure Applied to Display Evaluation	188
Human Motion Model-Based Simulation Drive Logic	190
Computational Vision Models	192
Image Sampling by Man and Machine	194
Cockpit Traffic Display Concept Tested in Conventional Jet Transport Simulator Under Instrument Workload Conditions	196
Army-NASA Aircrew Aircraft Integration (A^3I)	198
Crew Station R&D Facility	200
University Centers of Excellence	202
HUMAN FACTORS - SPACE	203
HORSES: An Expert System for the ORS	204
Intelligent Operator Aids: Operator Task Models	206
Advanced Wide Field-of-View Stereo Displays	208
Spatial Information Display Research for Enhanced Situational Awareness and Control	210
Image Management for Space Operations	212
Models of Color Constancy and Color Perception	214
Mockup Development for Space Station Proximity Operations	216
Crew Station Human Factors	218
Study of Cursor Control Devices in Zero-G	220
Workload Prediction: Remote Manipulation Arm Application	222

TABLE OF CONTENTS (CONT.)

	PAGE
HUMAN FACTORS - SPACE (Cont.)	
Computer Models of Position, Motion, and Strength of Human Operators	224
Space Station Operational Simulation	226
Factors Affecting Space Station Crew Performance	228
Advanced Space Suit Technology	230
Advanced Space Glove Technology	232
Extra Vehicular Activity (EVA) Performance Aids	234
SENSOR TECHNOLOGY	237
CCD Enhanced UV and X-Ray Response	238
Imaging X-Ray Spectrometer	240
Advanced Detectors for Space Applications	242
Development of an Antimony-Doped Silicon Integrated IR Array	244
Dewar Simulator	246
Excimer Lasers for Remote Sensing	248
Solid State Laser Transmitter Research	250
Laser Diode Array Technology	252
Catalyst Studies for CO_2 LIDAR	254
Tunable Solid State Laser Materials	256
Extended InAs/GaAs Strained-Layer Superlattices	258
New Superlattice Wavelength-Selective Detector	260
Superconductor-Insulator-Superconductor Mixer Based On Refractory Niobium Nitride	262
Quantum Well Fundamental Oscillator Development	264

LIST OF FIGURES

	PAGE
AUTOMATION AND ROBOTICS	
DEVISER-Voyager Off-Line Demonstration	3
PLAN-IT Expert System Scheduler	5
Automated Subsystem Management Advanced Life Support	7
Artificial Intelligence Research Group: Expert Systems	9
VLSI Image Chip/System	11
Roles of Human and Robotic Capability in Space	13
Space Telerobotics	15
Force/Torque Display and Control for Telerobotic Systems	17
Automation Performance Measures	19
Manipulator Control Mechanization Development	21
Force-Reflecting Hand Trigger Development	23
Human Stereo Vision Research for Space Teleoperation	25
Neuromuscular Factors Research for Force-Reflecting Manual Control in Zero-G Teleoperation	27
COMMUNICATIONS SYSTEMS	
Hoop Column Deployable Antenna System	31
The 15-Meter Model Electromagnetic Testing Verified Performance and Analytical Methods	33
Near Field Measurement Results	35
8-Beam Overlapping Cluster Feed For Mobile Satellite Applications	37
20 GHz Monolithic Transmit Module	39
Monolithic 30 GHz 5-Bit Phase Shifter	41
60 GHz TWT for Intersatellite Links	43
Efficient Solid State Power Amplifier Technology	45
Surface Acoustic Wave Resonator Oscillator (SAWRO)	47
Digital Filter Processor Chip	49
X-Band Dielectric Resonator Oscillator (DRO)	51
Very High Power Continuous Wave, Single Mode, Semiconductor Laser for Optical Space Communication, Fiber Communication and Recording	53
COMPUTER SCIENCES	
Massively Parallel Processor (MPP)	57
Software Management Environment for NASA	59
Simulation Model of the Software Life Cycle	61
Development of a Theoretical Basis for the Assessment of Software Redundancy	63
Research Institute for Advanced Computer Science (RIACS)	65
Center for Aeronautics and Space Information Sciences (CASIS)	67
Programmable Mask Technology	69
Optical Information Processing	71
Hyperspectral Analysis	73
Concurrent Processing Research	75
Intelligent Data Management	77
Heterogeneous Distributed Database Management	79

LIST OF FIGURES (CONT.)

	PAGE
CONTROLS AND GUIDANCE - AERONAUTICS	
Allowable Time Delays in Large Transport Responses	83
Optimal Control in Wind Shear	85
Full-Color Electroluminescent Flat-Panel Display	87
Verification Technology for Digital Flight Control Systems	89
The SURE Reliability Analysis Program	91
Digital System Lightning Upset Assessment	93
Total Energy Control System	95
Applications of State Estimation in Aircraft Flight-Data Analysis	97
Beacon Landing System (BLS) and Portable Tactical Approach Guidance (PTAG)	99
Rotorcraft Systems Integration Simulator Upgrade to Vertical Motion Simulator	101
Rotorcraft Air Combat Simulation	103
Integrated Airframe/Propulsion Control System Architectures	105
Advanced Automated Guidance Laws for High-Performance Aircraft	107
CONTROLS AND GUIDANCE - SPACE	
Control of Flexible Structures	111
Spacecraft Control Laboratory Experiment (SCOLE)	113
Structures/Controls Test - Configuration 1	115
Structures/Controls Test Facility - Configuration 2	117
System Identification	119
Non-Linear Simulation and Modeling	121
Unified Control Structure Modeling and Design	123
SHAPES: Spatial High-Accuracy, Position-Encoding Sensor	125
Automated Adaptive Control Subsystem	127
Advanced Precision Pointing Technology	129
Construction/Docking Technology	131
AOTV GN&C Research	133
Guidance, Navigation, and Control for Future Aeromaneuvering Vehicles	135
Fiber Optic Rotation Sensor (FORS)	137
STS GN&C System Technology Advanced Autopilot	139
STS Guidance and Control	141
DATA SYSTEMS	
Advanced Distributed System Networks	145
On-Board High Speed Adaptable Processor	147
Fiber Optic Data System	149
Fiber Optics Transceiver	151
VHSIC Processor Technology for Advanced Computing	153
VHSIC Technology Insertion	155
Advanced Information Processing System	157
Spaceflight Tera (10^{12}) Bit Optical Disk Buffer	159
Advanced Digital SAR Processor	161

LIST OF FIGURES (CONT.)

	PAGE
DATA SYSTEMS (Cont.)	
MAX Architecture	163
Advanced General Purpose Computer	165
Symbolic Processor Evolution Spaceborne VHSIC Symbolic Processor	167
HUMAN FACTORS - AERONAUTICS	
Field Studies of Flight Crew Transition to Advanced Technology Cockpits	171
Intelligent Cockpits: Pilot-Matched CDU Menu Organization	173
Artificial Intelligence Concepts for Flight Crew Aiding	175
The Causes and Effects of Runway Transgressions	177
Pilot Performance Factors in Short-Haul Flight Operations: A Field Study	179
Studies of Layover Sleep in International Long-Haul Flight Operations	181
Objective Assessment of Pilot Performance	183
Workload Assessment in Operational Settings	185
Workload Prediction	187
Mental Demand Effects on the Auditory Evoked Potential (AEP)	189
Human Motion Model-Based Simulator Drive Logic	191
Computational Human Vision	193
Image Sampling by Man and Machine	195
Cockpit Traffic Display Concept	197
Army-NASA Aircrew Aircraft Integration Program (A^3I)	199
Crew Station R&D Facility	201
HUMAN FACTORS - SPACE	
HORSES: An Expert System for the ORS	205
Space Automation: Intelligent Operator Aids	207
Advanced Wide Field-of-View Stereo Displays	209
Spatial Information Display Research for Enhanced Situational Awareness and Control	211
Image Management Technology	213
Models of Color Constancy and Color Perception	215
Mockup Development for Space Station Proximity Operations	217
Crew Station Human Factors	219
Study of Cursor Control Devices in Zero-G	221
Workload Predictions for Shuttle RMS Operations	223
Computer Models of Position, Motion and Strength of Human Operators	225
Space Station Operational Simulation (OpSim)	227
Factors Affecting Space Station Crew Performance	229
Ames AX-5 Hard Space Suit	231
AX-5 Hard Glove	233
EVA Performance Aids	235

LIST OF FIGURES (CONT.)

	PAGE
SENSOR TECHNOLOGY	
CCD Enhanced UV and X-Ray Response	239
Packaged X-Ray Chip for Imaging X-Ray Spectrometer	241
Advanced Earth Sciences Detector Research	243
Development of Antimony-Doped Silicon Integrated IR Array	245
Dewar Simulator	247
Innovative Laser Systems - Development of Excimer Lasers for Remote Sensing	249
Solid State Laser Transmitter Research	251
Laser Diode Array Technology	253
Catalyst Studies for CO_2 LIDAR	255
Tunable Solid State Laser Materials	257
Cross-Sectional TEM of an Extended InAs/GaAs Strained-Layer Superlattice	259
New Superlattice Device	261
D.C. Reactive Magnetron Sputtering Equipment	263
Submillimeter Local Oscillator Sources	265

Automation and Robotics

The objective of the Automation and Robotics Program is to exploit the potential of artificial intelligence and of telerobotics to decrease the cost of ground control and increase the capability and flexibility of space operations. Artificial Intelligence (AI) will be used to reduce the size of the ground control contingent, and telerobotics will be used to enable increased space servicing, assembly and repair.

The program has two foci, system autonomy and telerobotics. Each has a planned sequence of integrated evolutionary demonstrations from 1987 to 1995. Underlying the demonstrations are five core technology areas: sensing and perception, control execution, task planning and reasoning, control execution, operator interface, and system architecture and integration. Plans have been developed for the demonstration sequences, and research is underway in the five core technology areas. Coordination with the Defense Advanced Research Projects Agency (DARPA) is underway to leverage the relevant technology being developed under their Strategic Computing Initiative. Intercenter Memoranda of Agreement have been signed to facilitate the transfer of technology from the technology development centers to the user centers.

In sensing and perception, an intermediate-level computer vision system called PIFEX (Programmable Image Feature Extractor) has been developed which can detect hardware edges and vertices. In control execution, the use of computer vision and force/torque feedback has been used to automatically guide a pin to a close tolerance hole and insert it. In operator interface, a six degree of freedom force-reflecting generalizable master controller arm has been developed. In task planning, an artificial intelligence planner called (DEVISER) has been developed which, given a set of goals and a knowledge base of relevant actions, can generate a sequence of actions to implement those goals. In system architecture and integration, a joint venture with DARPA has been initiated to develop a spaceborne symbolic processor.

The initial telerobot demonstration will take place in late FY1987. It will comprise a two-arm telerobot which can perform simple servicing and assembly tasks on cooperative spacecraft using hand and power tools. It will include initial autonomous capability in terms of task primitives (such as open, close, screw, etc.). The initial systems autonomy demonstration will be in final preparation in FY1987 and will take place early the next year. It will comprise automated control (i.e., an intelligent aide) for a single mission operations subsystem, the Integrated Control Officer.

PROGRAM MANAGER: Dr. Melvin Montemerlo
NASA/OAST/RC
Washington, DC 20546
(202) 453-2743

Off-Line Demonstration Of DEVISER On Voyager-Uranus Sequence Generation

DEVISER, a knowledge based planner written by Dr. S. A. Vere at JPL, was demonstrated on Voyager sequencing in the first quarter of 1985. The off-line demonstration covered the Near and Post Encounter phases of the Uranus encounter. DEVISER's plans represented a respectable first cut in the hands of an expert operator. DEVISER was intentionally allowed to resolve all input conflicts and would receive manual intervention and guidance only as a last resort.

During the Voyager demonstration, DEVISER was given the same set of observation requests as the Voyager Science Investigation Support Team. These requests were processed by DEVISER in parallel with the manual sequence generation and integration process. DEVISER was provided ephemeris tables from MOVIE (Moving Observation View Interactive Editor) for instrument pointing and scan-platform slewing calculations. The inputs to DEVISER and the resulting sequences were analyzed with GREAT (Graphic Representation Editing Aid Timeline program) and then plotted in timeline format.

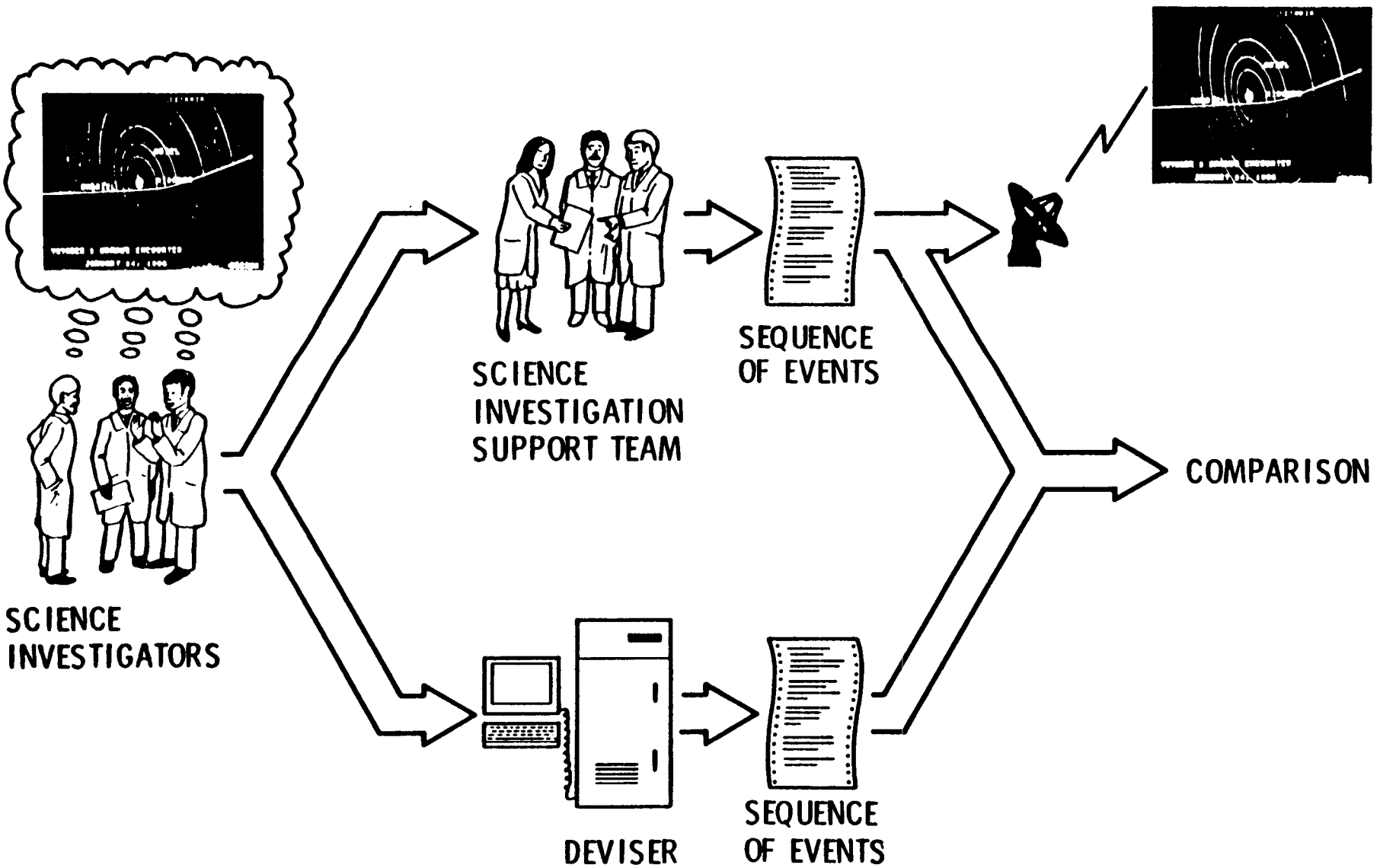
During the Near Encounter planning demonstration DEVISER satisfied just under 60 requests out of 97 submitted. These requests correspond to roughly 300 low-level activities and were planned by DEVISER in 2.5 hours. Human sequence generation and integration to the same level of accuracy would have required between one to two work-weeks of effort. Many of the 37 requests DEVISER deleted could not have been satisfied as requested due to spacecraft resource over-subscription. However, during this time the manual process would have involved significant requestor-planner interaction, resulting in request modification and a better final sequence.

The Post Encounter planning demonstration yielded similar results, except that some 700 data rate changes had to be incorporated into the plan in addition to the 190 requested observations. Due to memory limitations, the resulting 890 requests and data rate changes had to be processed in eight overlapping batches. It took DEVISER 40 hours to process these batches and resulted in approximately 120 requests of the 190 being satisfied.

The Voyager project has requested that DEVISER be tested again on Uranus-Neptune cruise sequences following the January 1986 Uranus encounter.

TECHNICAL CONTACT: Wayne Schober, JPL (818) 354-8581

DEVISER-VOYAGER OFF-LINE DEMONSTRATION



PLAN-IT: An Expert System Schedule Planner

PLAN-IT is an expert system schedule planner. It complements DEVISER's (a knowledge based configuration planner written at JPL) local configuration planning capability by allowing global planning considerations to be taken into account when reordering events in a plan.

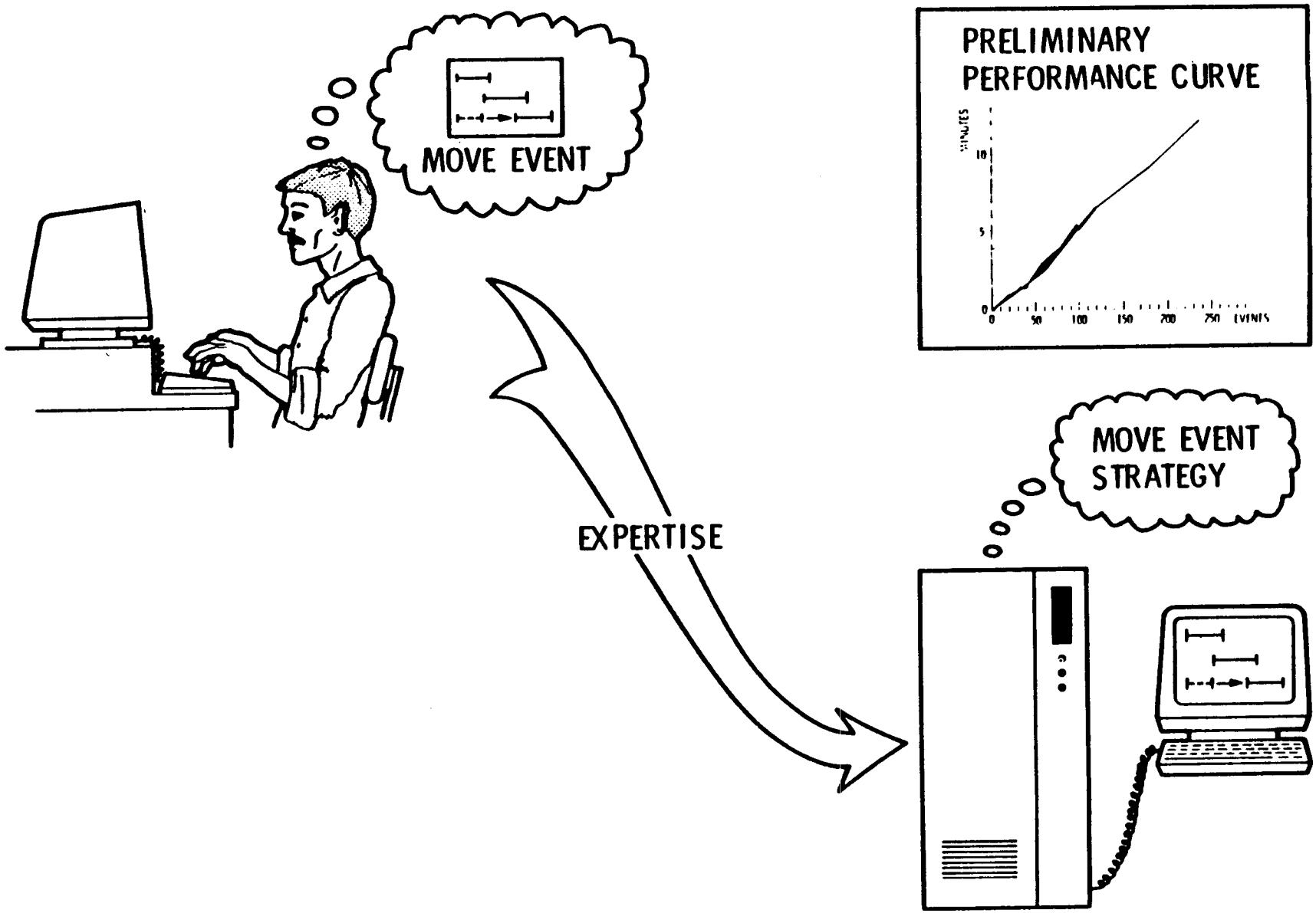
Development of PLAN-IT was initially started in response to Spacelab planning problems. Spacelab represents a wide range of planning problems where detailed configuration changes, or steps, have been preplanned into larger activities. The planning problem involves the reordering and interleaving of these activities into a conflict free timeline. The core of PLAN-IT holds the knowledge needed to move or alter events, how the individual steps relate to activities and how to measure the level of conflicts and resource utilization. Expert strategies overlay this core and allow PLAN-IT to develop schedules which resolve utilization conflicts in a manner which mimics the expert who provided the expertise.

Early evaluation of PLAN-IT has shown that even simplistic strategies can result in remarkably good plans with a very favorable response time. These evaluations have also shown the response time to be roughly linear with the number of steps in the activities to be planned. The linear nature of the response time degrades only when the limits of the host hardware are approached. The PLAN-IT user interface allows PLAN-IT to be used both in fully automatic mode and in a highly interactive mode. In the interactive mode, PLAN-IT acts as a very intelligent timeline editor showing the user where conflicts exist and where usage gaps occur.

Current PLAN-IT development includes not only the Spacelab application but also an experimental application to Deep Space Network scheduling and Space Station power re-scheduling. In all of these applications the main planning problem lies in the re-ordering of activities, not the planning of the steps in the activities.

TECHNICAL CONTACT: Wayne Schober, JPL (818) 354-8581

PLAN-IT
EXPERT SYSTEM SCHEDULER



Automated Subsystem Management

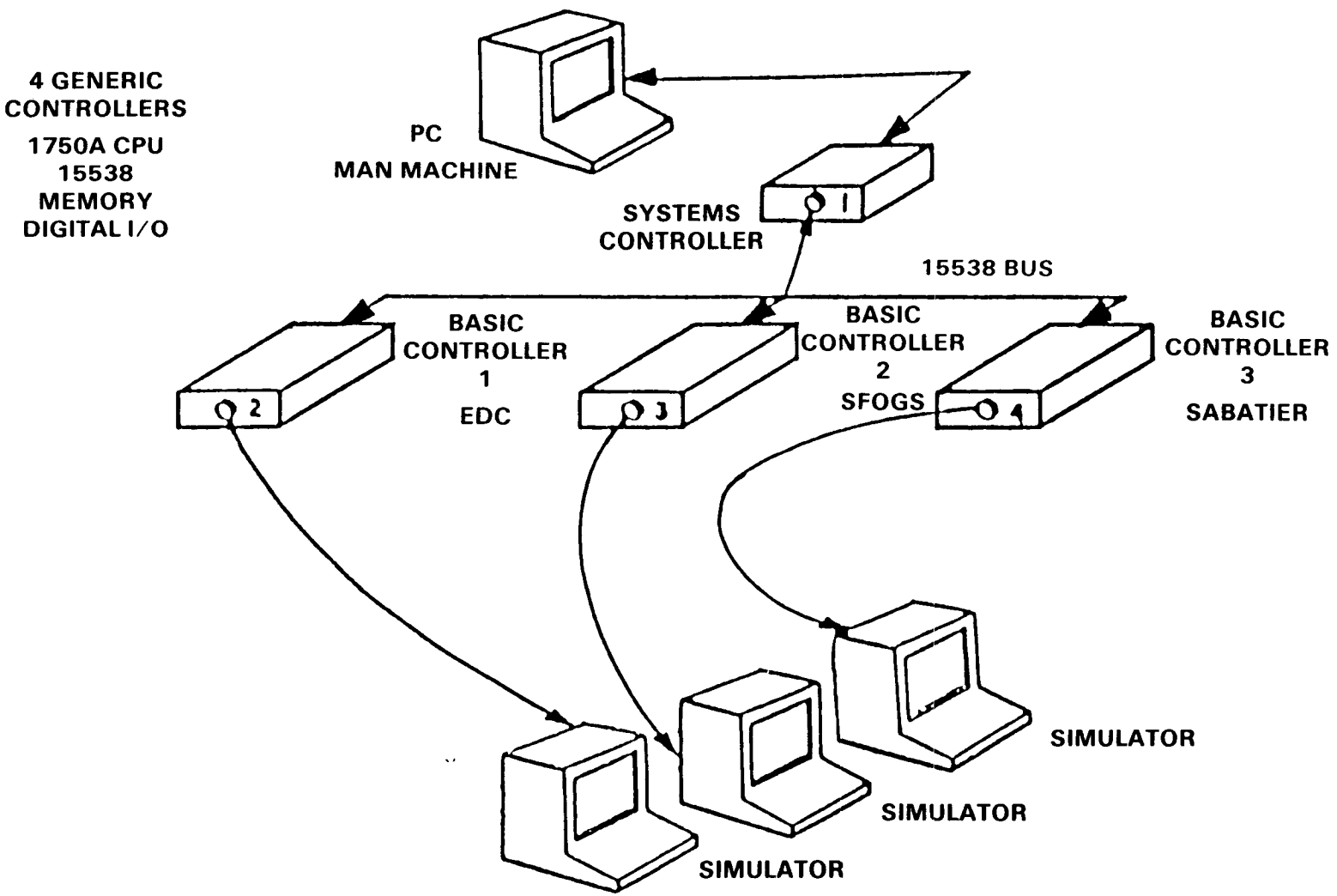
The objective of this program is to develop and demonstrate a generic automation system for the control and monitoring of Space Station systems, using the ECLSS (Environmental Control and Life Support System) as the demonstration system. The end products are to be three "subsystem simulators" for the three major air revitalization subsystems, three "basic controllers" which control and monitor each subsystem, a "system controller" to control and monitor the integrated subsystem processes, and a "Man-Machine Interface" (MMI) from which the operator can interact with the subsystems through their controllers.

The activity of the last year has primarily been focused on the detailed design and fabrication of the control system hardware and software. The basic controllers and the system controller are essentially identical in design. A generic family of cards then allows each controller to take on the specific nature of either the basic or system controller. The software development effort has concentrated on coding and debugging the software responsible for the communications between the simulators, the basic controllers, the system controller, and the MMI. The ECLSS applications software in the simulators and the controllers, the operating system software, and the MMI software are all proceeding in parallel. The first test of a "single string" of software from the MMI to the simulators using the communications software is expected to take place in late 1985.

TECHNICAL CONTACT: Frank H. Samonski, JSC (713) 483-4823

AUTOMATED SUBSYSTEM MANAGEMENT
ADVANCED LIFE SUPPORT

Baseline Physical Configuration



Artificial Intelligence Research Group: Expert Systems Programs

The Artificial Intelligence Research Group effort in Expert Systems resulted in completion of several projects in FY85, and research and development of additional systems which support the Systems Autonomy and TeleRobotics programs was continued. The effort to develop an integrated intelligent command and control system, called PEER, has been greatly advanced by these results, and testing of a co-operating expert systems approach is scheduled for FY86.

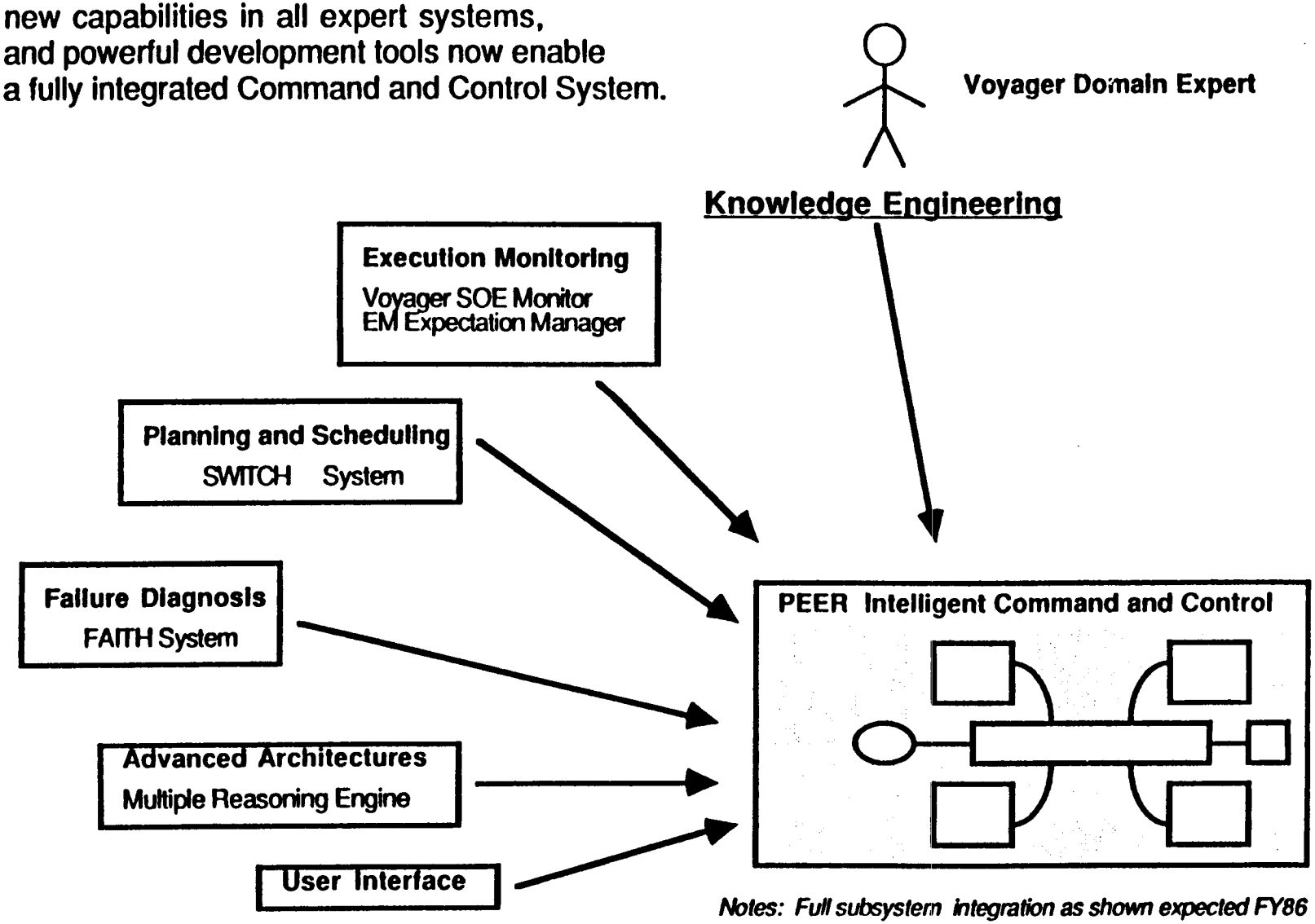
Significant new capabilities and performance enhancements were added to the SWITCH planner and FAITH diagnosis systems. To support contingency planning and error recovery, procedures for the automatic generation of goals, isolation of critical plan segments, and plan revision after discrepancy detection were added to SWITCH. FAITH was extended to provide simulation of system components, manipulation of basic assumptions during reasoning, and the generation of some natural language explanations for its reasoning processes. Performance enhancements halved execution time for typical problems in FAITH and resulted in considerable memory savings in both systems. Extensive knowledge-engineering was carried out for realistic scenarios involving the Voyager 2 Photo-Polarimeter Sensor. Preliminary performance results from the Planner and Diagnostician Expert Systems indicate the viability of this approach for encoding valuable human expertise. A programmable hardware interface to the Voyager telemetry stream has been completed. Installation will allow direct testing of execution monitoring and fault diagnosis in FY86.

Research into advanced AI system architecture has yielded the design and implementation of several powerful software tools which form an integrated system called the Multiple Reasoning Engine (MRE). A blackboard communications module with a spontaneous computation tool has been completed. Nearing completion are a memory structure module, a multiple inference process control module, reasoning engine design language, and a graphic display debugging tool. The MRE modules facilitate research and development of knowledge-based systems.

TECHNICAL CONTACT: Wayne Schober, JPL (818) 354-8581

ARTIFICIAL INTELLIGENCE RESEARCH GROUP: EXPERT SYSTEMS

Highlight: Extensive knowledge-engineering, new capabilities in all expert systems, and powerful development tools now enable a fully integrated Command and Control System.



Notes: Full subsystem integration as shown expected FY86

Machine Vision

The objective of the JPL program in machine vision is to develop a hardware/software system which can provide visual object recognition, acquisition, tracking and task verification for space activities. These activities include assembly, service, and repair of space structures and satellites, as well as visual guidance of mobile platforms in free space or on planetary surfaces. In prior years, a visual tracking algorithm for unlabelled objects was developed and demonstrated to run in real-time. An object acquisition algorithm was designed which incorporates several modules, including a feature tracker, motion stereo, stereo matcher, model matcher, and tracking initializer. Previously, the feature tracker, motion stereo, and stereo matcher were coded and fully debugged. Also, an advanced pipeline vision system known as PIFEX (Programmable Image Feature Extractor) was conceived and development begun.

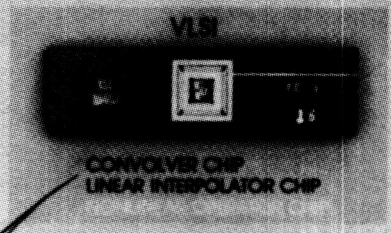
Activities in FY 85 focused on continued PIFEX development and continued coding and debugging of the object acquisition software. Accomplishments included finishing and some debugging of the PIFEX prototype, defining a PIFEX compiler language (including a Backus-Naur formal specification of syntax), defining techniques for visual guidance of mobile platforms (which led to DoD funding for rover work directly applicable to planetary surface exploration), and coding and debugging of the Model Matching module and partial coding of the Tracking Initializer.

Planned activities in FY 86 include an integrated demonstration of real-time acquisition and tracking of a moving simulated satellite, and final debugging of the PIFEX wire-wrap prototype and production of a limited run of printed circuit modules.

TECHNICAL CONTACT: Brian Wilcox, JPL (818) 354-6508

VLSI IMAGE CHIP/SYSTEM

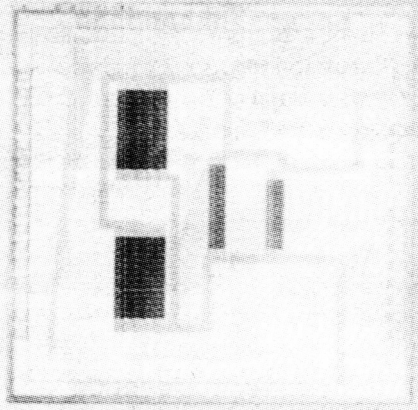
A programmable Image Feature Extraction System (PIFEX) using custom designed VLSI chips is under development. PIFEX is a real-time pipelined image processing system that can perform 10^{11} 12-bit operations per second. It offers versatile robotic video processing capabilities in computer vision and image manipulation applicable to space station construction/ teleoperation, factory automated manufacturing, and roving vehicle navigation.



COMPUTER VISION AND ROBOT CONTROL LABORATORY SYSTEM ARCHITECTURE

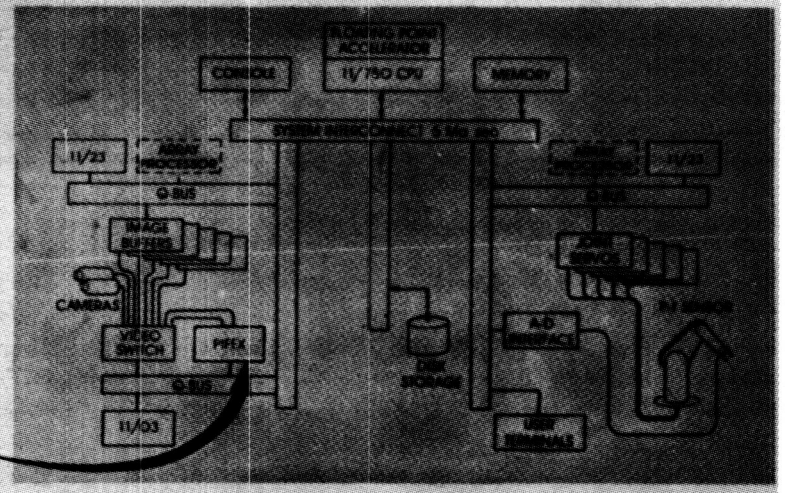
REAL TIME PIPELINED PROCESSING

- **IMAGE PROCESSING FUNCTIONS:**
  1. GRADIENT OPERATION
  2. VERTEX DETECTION
  3. NEAREST NEIGHBOR OPERATION
- **APPLICATIONS:**
  1. VISION SYSTEM FOR OBJECT TRACKING
  2. STEREO CORRELATION
  3. DEPTH MAP CREATION

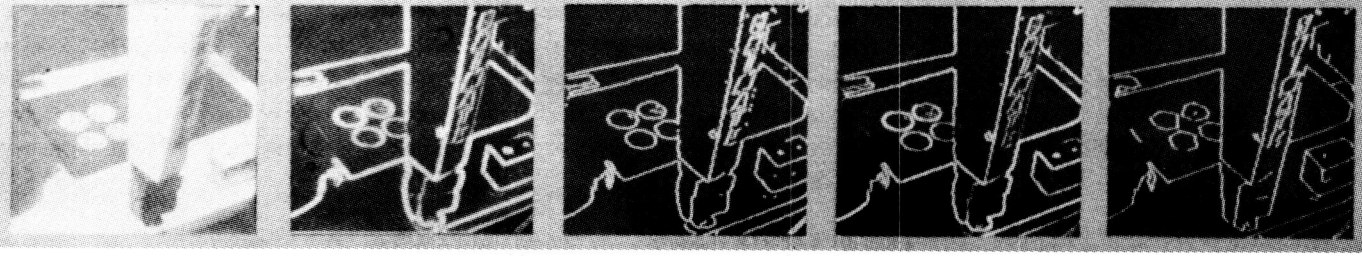


MODULAR PIFEX CIRCUIT CARD

PIFEX--ARRAY OF MODULAR CARDS



LOCAL FEATURE IMAGE PROCESSING



Roles of Human and Robotic Capability in Space

For almost any task to be performed in space, a variety of techniques may be applicable. An important decision criteria for future space endeavours is to identify the optimum roles of humans and machines for any particular task of interest. The approach often suggested, that of maximizing robotic involvement and attempting to eliminate humans from all tasks, does not take into account the flexibility, intelligence, and dexterity of the on-site human. The possible roles of humans and machines range from purely manual activities, through machine support and augmentation, teleoperation, supervisory control and automation, all the way to applications of artificial intelligence techniques for fully autonomous systems.

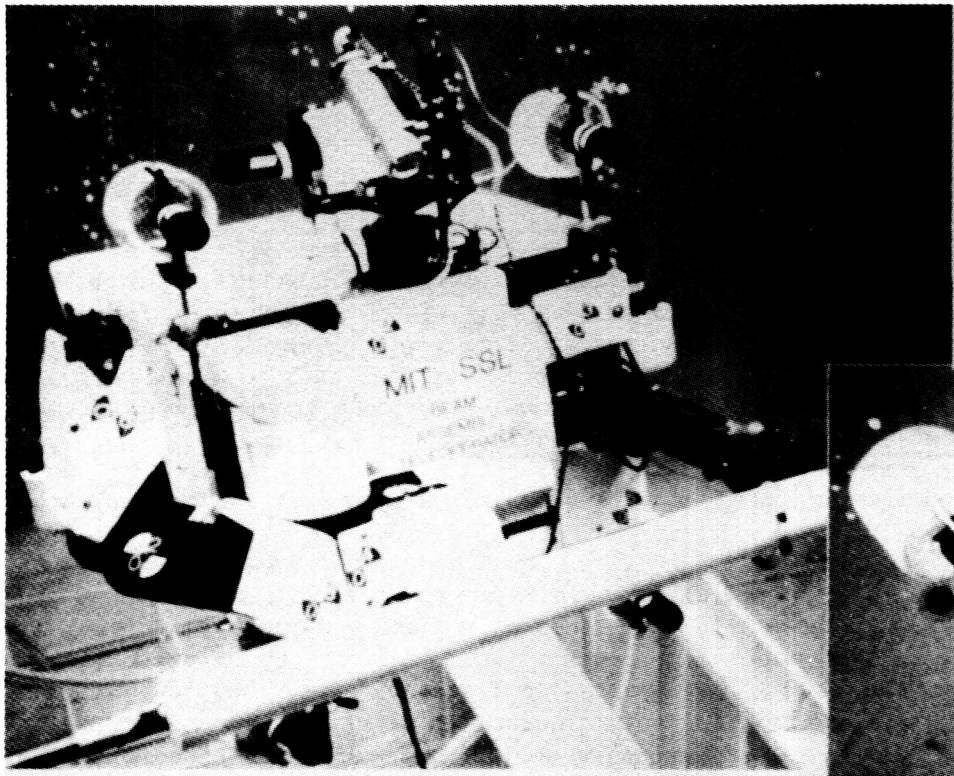
The Massachusetts Institute of Technology (MIT) Space Systems Laboratory has been investigating this range of capabilities for almost a decade now, with the intent of developing a large enough data base in available ground-based simulation media to arrive at a meaningful estimate of human and machine roles for particular tasks. The task chosen for initial study was that of large space structure assembly, which provides an important subject for extensive study, without getting into fidelity issues associated with other possible study options such as satellite servicing.

In the left-hand picture (opposite figure), MIT test subjects are assembling a large space truss formed of 12-ft. long individual struts. The structural configuration under study in this print is a tetrahedral truss, which is a building block for many of the proposed large space structures. In MIT tests over the past eight years, structural assembly test subjects have exhibited uniformly high productivities and rapid learning rates, as well as an instinctive adaptation to the weightless environment. This research has led to the development and successful flight test of EASE, the Experimental Assembly of Structures in EVA. Flown on Shuttle flight 61-B, two crewmen repeatedly assembled and disassembled a six-element tetrahedron, quantifying learning rates and productivities in the actual weightless environment.

Although the manual assembly task was the first modelled, and is therefore the most well developed, much activity at MIT over the past few years has been the development of a space teleoperator for the neutral buoyancy environment. The Beam Assembly Teleoperator (BAT) is designed to assemble the same structures underwater as those used in the baseline MIT test series, the components of which are also identical in mass properties to those flown on 61-B. In this manner, data on teleoperated assembly may be collected through neutral buoyancy simulation and used to correlate the performance of flight teleoperators. Planned near-term growth options include the addition of processing and symbolic manipulation to the control system in order to expand the capabilities of BAT beyond those of a simple teleoperator, into the realm of supervisory control and limited mission autonomy. Through devices such as BAT and other robotics vehicles developed in-house, the aim of MIT is to develop a quantitative, verified data base which may be used to estimate the optimum role of humans on-site for any particular task.

TECHNICAL CONTACT: Dave Akin, MIT (617) 253-3626

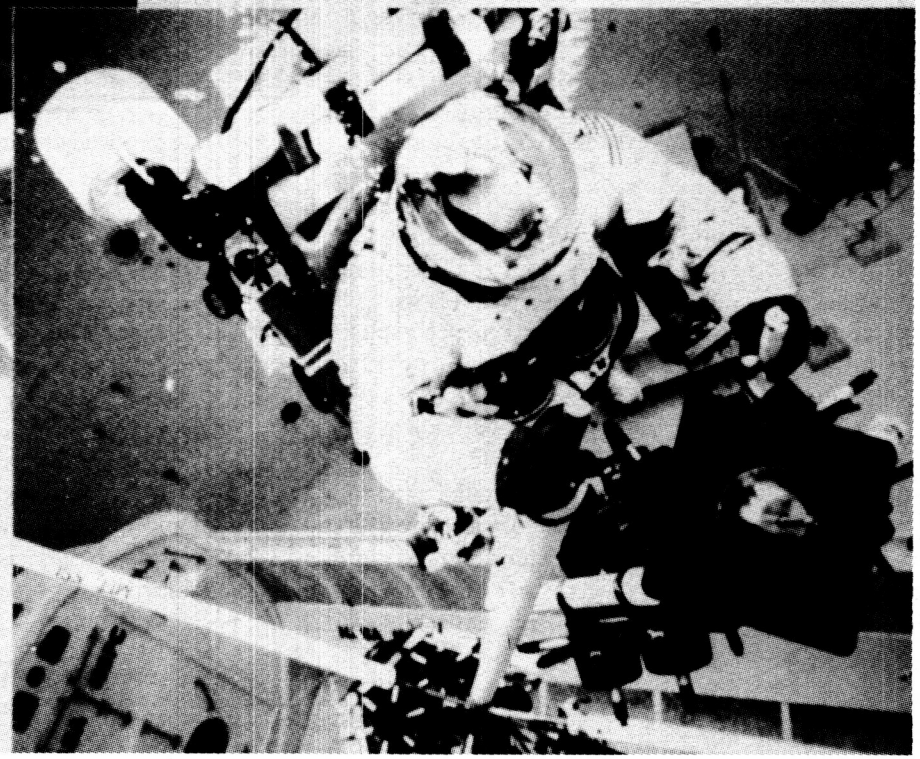
ROLES OF HUMAN AND ROBOTIC CAPABILITY IN SPACE



REMOTE MANIPULATION

TELEOPERATION

ON-SITE MANIPULATION



EXTRA VEHICULAR ACTIVITY

NASA

Telerobotics Technology Integration and Demonstration

The objective of this program is to develop a phased set of ground-based telerobot demonstrations which show an evolving capability to usefully complement manned space activities. By integrating advanced sensing, robotic manipulators, and AI-based control under human-interactive supervision, such telerobots provide automated support to a variety of mission tasks which include space assembly, maintenance, repair, and telescience. This human-machine synergism has potenteial to substantially increase astronaut productivity, reduce cost of support resources, and extend mission capability and reliability.

For telerobots to support or replace astronaut activity, they must be responsive to multiple tasks and environmental uncertainty. This requires the capabilities for planning activity sequences from an operator's high-level description; to perceive, navigate, and dexterously manipulate within occluded workspaces; and to intelligently monitor and correct anomalies in robot behavior. To this end, developments are required in real-time machine vision, AI expert/planning systems for logical and spatial reasoning, algorithms and force-reflecting mechanisms for cooperative multi-arm manipulation, operator displays and interfaces for shared/traded hierarchical control, and architectures enabling run-time integration of these functions.

This program activity was initiated in June, 1985, as an augmentation of ongoing research in machine vision, teleoperation, and AI systems for task planning and failure diagnosis. The first telerobot demonstration is scheduled for FY 87 and will show capability for cooperative dual-arm execution of a precompiled, routine satellite servicing task. JPL has specified high-level functional requirements for all FY 87 telerobot subsystems, defined a supporting system functional architecture and test facility, and developed a detailed implementation plan for telerobot technology development and integration. FY 86 work will refine existing algorithms and software for system integration, and, initiate fabrication of telerobot subsystems. In FY87 the telerobot test bed will be emplaced, demonstrated for the target tasks, and made available for continuing test and evaluation of participating center technologies.

TECHNICAL CONTACT: Paul Schenker, JPL (818) 354-2681

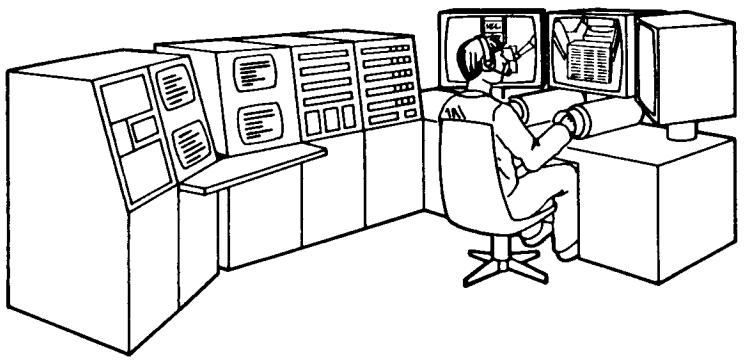
SPACE TELEROBOTICS

1987 DEMONSTRATION

STATIONARY ROBOT, SIMPLE SPACECRAFT SERVICING TASKS, SUPERVISORY CONTROL

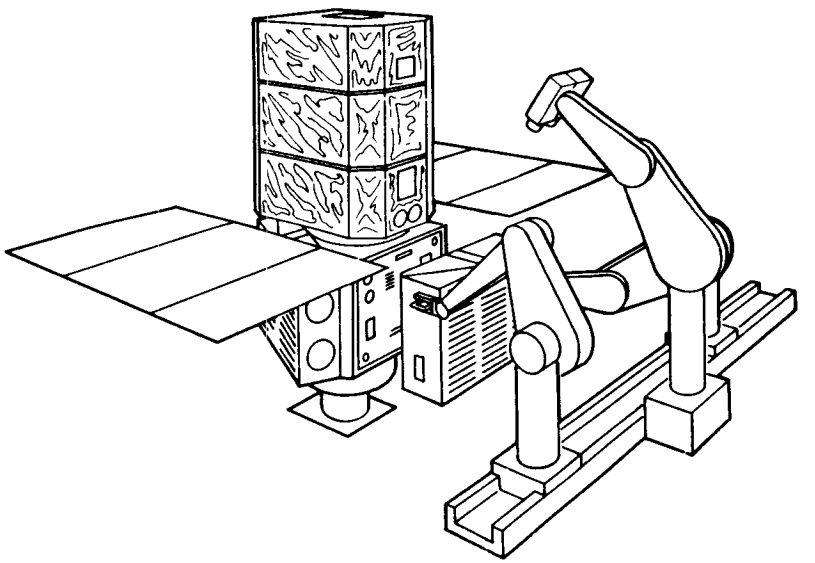
TECHNICAL ADVANCES

- SPACE SERVICING PRODUCTIVITY IMPROVEMENT
- DUAL-ARM COOPERATION
- MANUAL/POWER TOOL HANDLING



CONTROL STATION

- STEREO DISPLAYS
- TWO-ARM BILATERAL FORCE - POSITION CONTROL
- VOICE RECOGNITION/SYNTHESIS
- INTERACTIVE TASK PERCEPTION
- OFF-LINE INTERACTIVE PLANNING



RUN TIME CONTROL/PERCEPTION SYSTEM

- AUTOMATIC STEREO TASK FRAME ACQUISITION AND TRACKING
- AUTOMATED SYSTEM CONTROL AND SEQUENCING
- AUTONOMOUS/INTERACTIVE TASK EXECUTION AND MONITORING
- TELEOPERATOR CONTROL AS REQUIRED

Force/Torque Display and Control for Telerobotic Systems

This program will enable a telerobotic system to function with higher levels of autonomy while retaining manual control capability by the use of force/torque feedback from a robotic end effector to control and monitor the movements of a manipulator arm in a telerobotics system. Signals from strain gages in the fingers of the end effector are fed back to the manipulator controller, through computers, giving a sense of touch to the automated system as it inserts a peg into a close tolerance hole. The peg-in-hole task is representative of a large class of spacecraft servicing tasks that require precise alignment of an object with receptacle; for example, a bolt in a hole, or a module in a mounting rack.

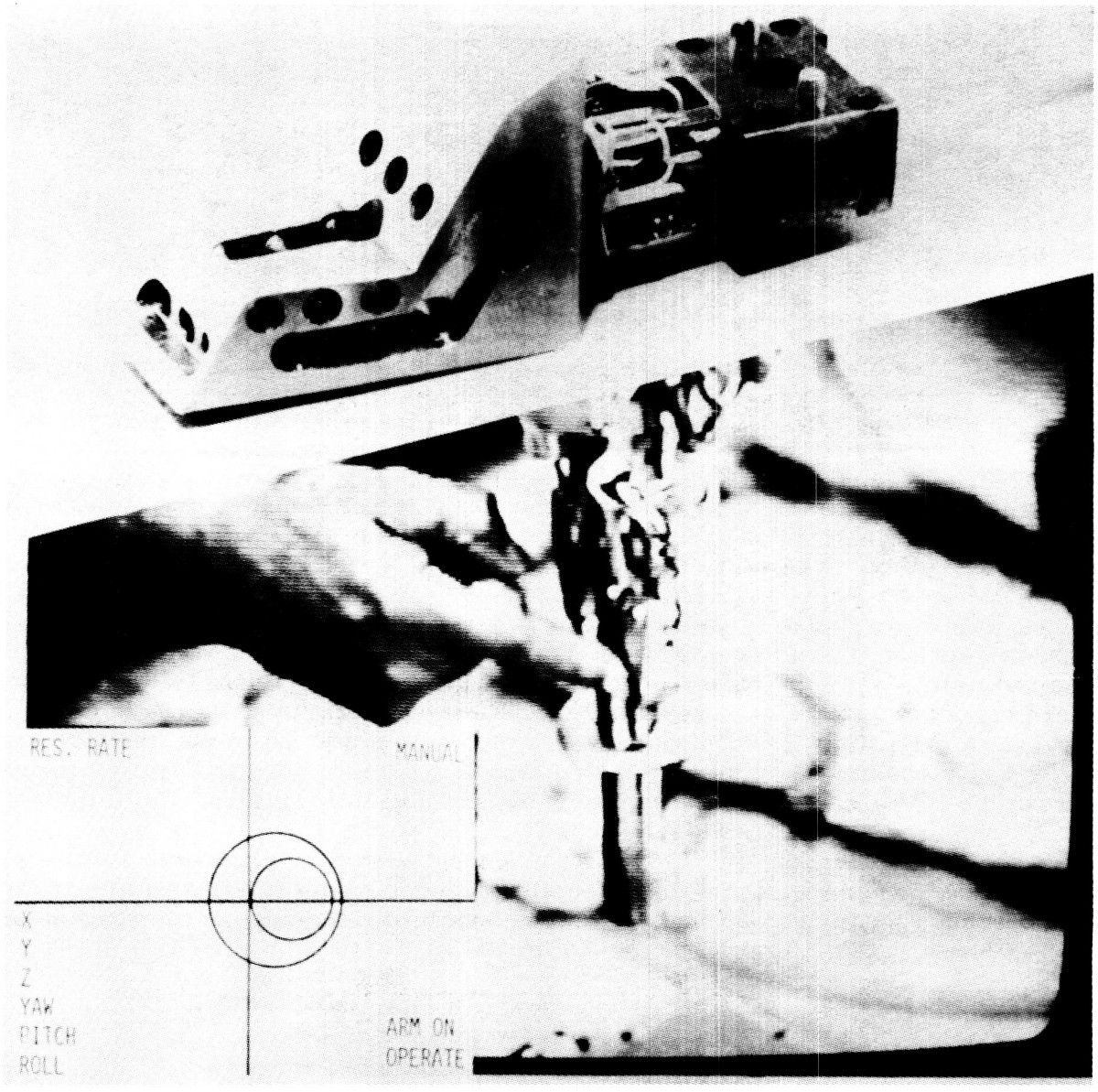
A computer-generated graphic display of the force/torque information is provided, enabling the operator to monitor the automated system, or to perform the task manually, if desired. The display appears as two concentric circles representing the ends of a cylindrical object, such as a peg. Signals from the fingers cause the circles to move concentrically in response to forces and differentially in response to torques, giving the operator an easily interpreted visual representation of nonvisual information. The picture in the accompanying figure shows pressure being applied to the end effector. The concentric circle operator aid is also displayed.

Laboratory experiments show that use of force/torque feedback results in fully automated alignment of the peg with the hole. Displaying force/torque information to a human operator facilitates insertion or extraction of the peg with more precision than when using vision information alone.

Additional peg-in-hole experiments and analytical studies will be conducted to assess the performance of other types and locations of force/torque sensors. Also, future research will investigate force/torque feedback in the performance of tasks that are more representative of those required for satellite servicing and assembly.

TECHNICAL CONTACT: Alfred Meintel, Jr., LaRC (804) 865-3871

FORCE/TORQUE DISPLAY AND CONTROL FOR TELEROBOTIC SYSTEMS



Automation Performance Measures

The objective of this program is to develop performance measures which can be used to compare the effectiveness of control techniques and to evaluate the level of operator workload in telerobotic tasks. Eventually, such measures will be used to predict system performance and to compare design concepts.

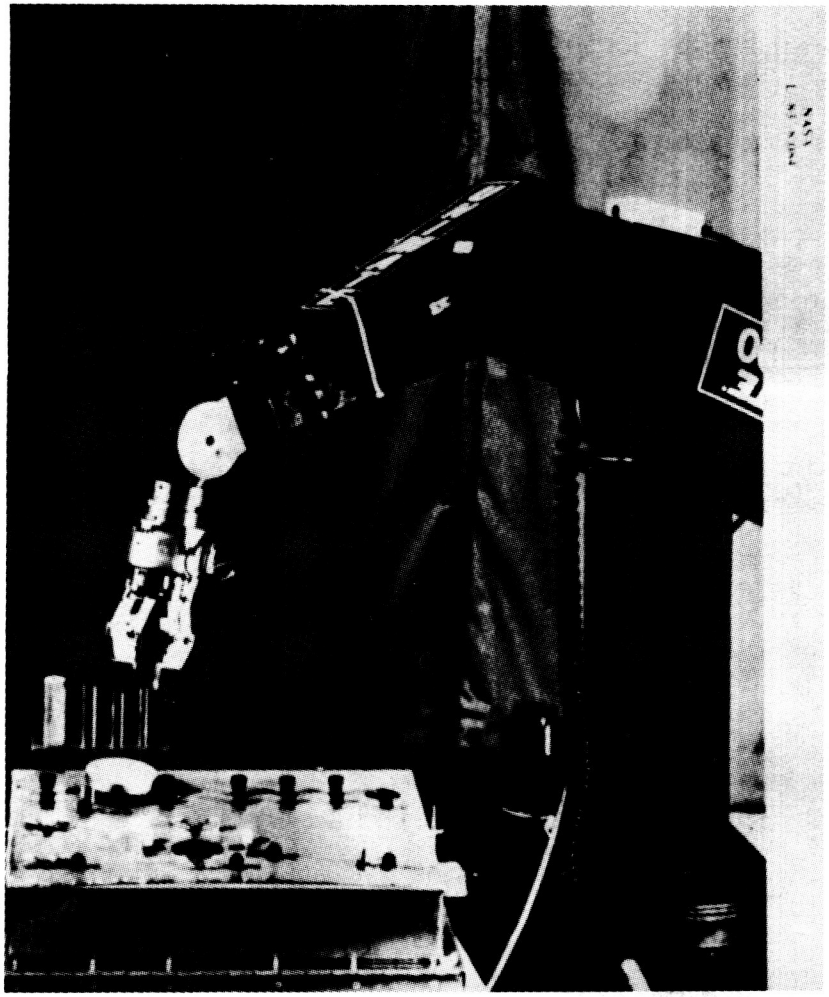
The approach being taken is to examine tasks which can be accomplished by various levels of automation, and then to measure the input control requirements and task performance. Several tasks are being studied. Each of these tasks can be performed at levels of human input that range from commanded motions of each manipulator link individually (one at a time) through levels in which the computer synthesizes coordinated motions of several links simultaneously in response to higher-level commands to the system. At the highest point (fully automated), the system performs the entire task from a single human command. Inputs made by subjects through various teleoperator modes are recorded at the different levels of automation and are used in developing relative performance measures.

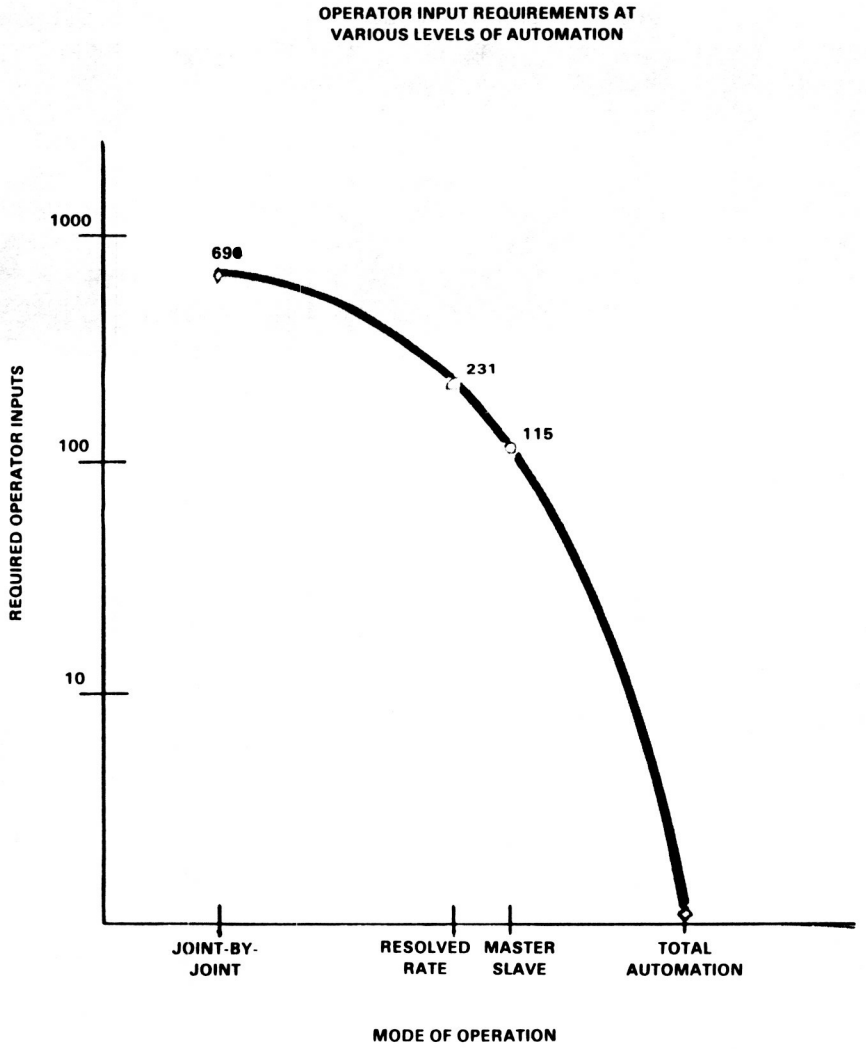
The preliminary results shown on the figure on the opposite page were obtained from several subjects performing a simple teleoperator task on a task board with an industrial manipulator. For this task, with higher levels of input, the level of human involvement decreases from 604 inputs for the least automated case, to a single input in the fully automated case.

Future efforts will extend the data base to other tasks and telerobotic systems, and evaluate potential predictors of automation performance.

TECHNICAL CONTACT: Alfred Meintel, Jr., LaRC (804) 865-3871

AUTOMATION PERFORMANCE MEASURES





Manipulator Control Mechanization Development

The long-range objective of this task is twofold: (1) to develop and evaluate a modular and expandable distributed microcomputer hardware and software system matching the natural needs of real-time mechanization of manipulator control in space teleoperation; and (2) to develop prototype smart end effectors with microcomputers integrated into the end effectors, matching interfacing requirements to the overall distributed manipulator control system. The smart end effector concept includes mechanical sensing and control dexterity built into the end effector which has to be matched by built-in local data handling and computing power. The natural needs of manipulator control in space teleoperation include: (a) distribution of real-time control computing power between control station and remote manipulators equipped with smart end effectors and tools and (b) the use of alternative and interchangeable control techniques like (i) generalized force-reflecting hand controller with force-reflecting hand trigger, (ii) sensor-referenced automatic control and (iii) supervisory control, including interface to expert systems for planning task controls. The notion of expandable control mechanization includes the capability of extending the control to multiple-arm space teleoperators.

The main deliverables of this task are: (1) a distributed and modular microcomputer system interfaced to (i) force-reflecting hand controllers/triggers, (ii) remote robot arms, (iii) smart end effectors/tools, (iv) higher level supervisory/planning controllers, (v) graphic displays, (vi) computer controlled TV system and (vii) machine vision; (2) real-time control software for force-reflecting manual and for model- and sensor-referenced automatic controls; and (3) local computing systems integrated into smart end effectors.

The FY85 accomplishments include. (1) expansion or a microcomputer network to handle computer graphic displays; (2) partial integration and debugging of distributed microcomputer hardware and software system interfaced to a PUMA 560 robot arm and to a generalized force-reflecting hand controller; and (3) design and fabrication of a smart hand mechanism for a PUMA 560 robot arm, including grasp force sensors, a six DOF force-torque sensor and multifunctional claws.

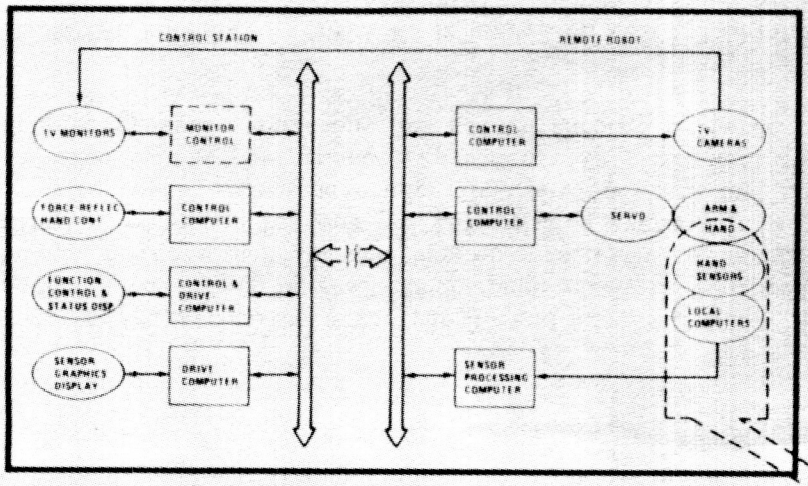
A main feature of the distributed control computing system is the separation of control computing development from control computing instrumentation. For software development a VAX 730 computer is employed. For real-time control instrumentation NS32016 microcomputers are used in the distributed computer network. The software is written in C language, using a UNIX operating system. The software developed on VAX is debugged and downloaded through a crosscompiler to the NS32016 machines.

Ongoing and future work includes: (1) completion of computing system integration and debugging for a one-arm system interfaced to a force-reflecting hand controller and to a simple supervisory controller; (2) completion of smart hand control development, including its interface to the overall system; and (3) expansion of the computer control system to a two-arm control system and to the control of a multiple TV camera system.

TECHNICAL CONTACTS: Antal K. Bejczy, JPL (818) 354-4568
Ronald S. Dotson, JPL (818) 354-5728

MANIPULATOR CONTROL MECHANIZATION DEVELOPMENT

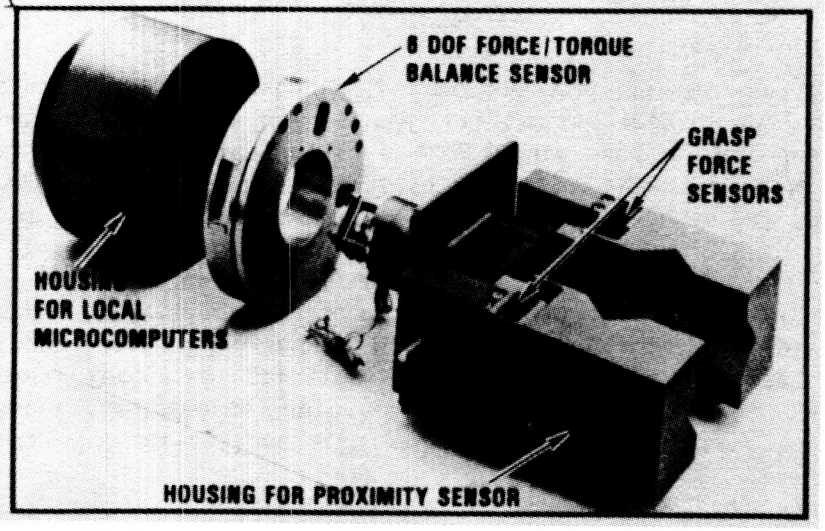
DISTRIBUTED MICROCOMPUTER NETWORK



OBJECTIVES:

- DEVELOPMENT OF A DISTRIBUTED COMPUTING HARDWARE AND SOFTWARE SYSTEM MATCHING THE NATURAL NEEDS OF INTERACTIVE MANUAL AND AUTOMATIC CONTROL OF REMOTE MANIPULATORS IN SPACE TELEOPERATION
- DEVELOPMENT OF A PROTOTYPE SMART ROBOT HAND WITH MICROCOMPUTERS INTEGRATED INTO THE HAND, AND THE WHOLE SUBSYSTEM INTEGRATED WITH THE OVERALL DISTRIBUTED MANIPULATOR CONTROL SYSTEM

SMART HAND MECHANISM FOR PUMA 560 ROBOT ARM



FY'85 ACCOMPLISHMENTS:

- PART-INTEGRATION AND DEBUG OF DISTRIBUTED MICROCOMPUTER HARDWARE AND SOFTWARE SYSTEM INTERFACED TO PUMA 560 ROBOT ARM AND TO A GENERALIZED FORCE-REFLECTING HAND CONTROLLER
- DESIGN AND FABRICATION OF A SMART HAND FOR PUMA 560 ROBOT ARM

FY'86 ACTIVITIES:

- COMPLETE SYSTEM INTEGRATION AND DEBUG FOR A ONE-ARM SYSTEM
- COMPLETE SMART HAND CONTROL SYSTEM
- INITIATE EXPANSION TO A TWO-ARM CONTROL SYSTEM

Force-Reflecting Hand Trigger Development

The long-range objective of this effort is to upgrade generalized force-reflecting hand controllers with active force-reflecting hand triggers enabling the operator to control grasp forces of a mechanical hand with a sense of "feel" which is required for dexterous control of remote manipulator tasks. Force-reflecting or bilateral control is an essential contributing element to the operator's "telepresence" in teleoperation. This control provides both dynamic and implicit kinematic synchronization between the operator's manual control activities and the motion and dynamic activities of a remote manipulator. This synchronization enables the operator to control with high manual fidelity.

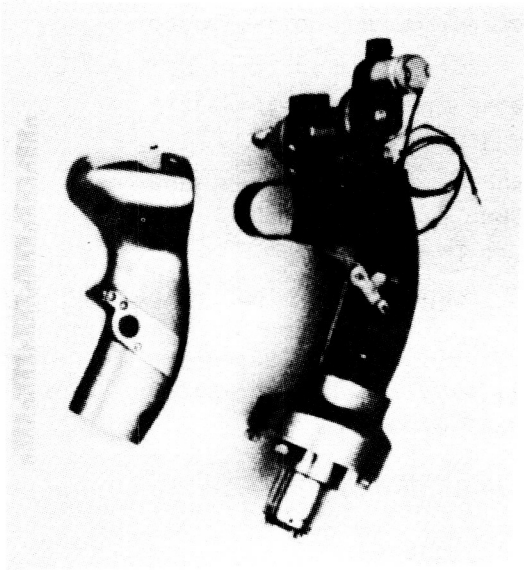
The generalized force-reflecting hand controller developed at JPL for experimental studies related to potential space applications does not have a force-reflecting hand trigger. Hence, the short range objective of this effort is to develop a prototype force-reflecting hand trigger for control experiments leading to a more mature hand trigger design which can be integrated with a generalized force-reflecting hand controller. It is noted that two fundamental questions are associated with hand trigger design: (i) how many control functions can be built into one hand trigger, and (ii) how will the built-in functions interfere with other manual control activities.

The FY85 accomplishments include: (1) publication of a state-of-the-art technology survey and evaluation of hand controllers for teleoperation, JPL publication 85-11; (2) development of an innovative design for a force-reflecting hand trigger with independent position and force control; (3) fabrication and assembly of the electro-mechanical parts of a stand-alone unit; (4) development of control electronics design, including control software; and (5) simulation software development for system test on an IBM PC.

Ongoing and future work includes: (1) completion of hand trigger control system development interfaced to a simulated robot hand and to a real robot hand which is equipped with the appropriate sensors and controls; and (2) conducting human factors performance experiments with the stand-alone force-reflecting hand trigger with and without graphic display of grasp forces, and following a systematic performance test schedule. The test schedule includes: static and dynamic tests, free and constrained motion tests and tracking tests with disturbances. The fundamental question to be answered by the performance experiments is: how well can the operator maintain desired gripper clamp force, imparted by trigger pressure/position, and sensed through a "force reflector" in the new force-reflecting hand trigger.

TECHNICAL CONTACTS: Antal K. Bejczy, JPL (818) 354-4568
Paolo Fiorini, JPL (818) 354-0351

FORCE-REFLECTING HAND TRIGGER DEVELOPMENT



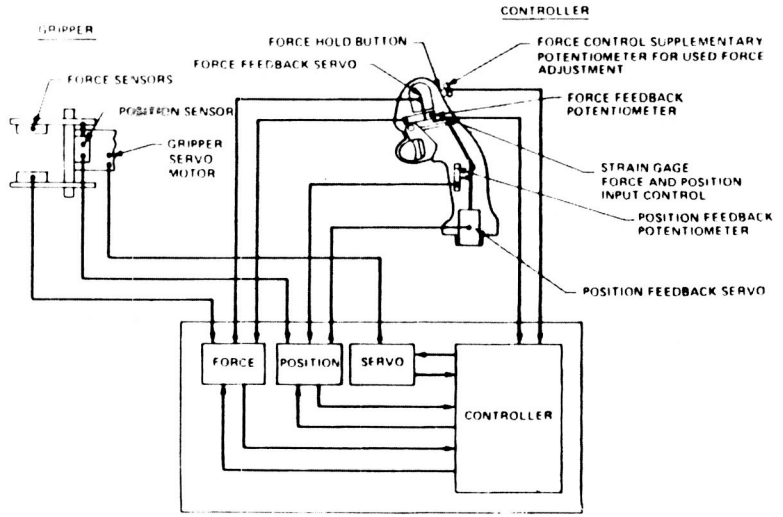
OBJECTIVE: DEVELOPMENT OF FORCE-REFLECTING HAND TRIGGERS FOR FORCE-REFLECTING HAND CONTROLLERS ENABLING THE OPERATOR TO CONTROL GRASP FORCES WITH "FEEL" IN DEXTEROUS REMOTE MANIPULATOR TASKS

FY'85 ACCOMPLISHMENTS:

- DEVELOPMENT OF AN INNOVATIVE FORCE-REFLECTING HAND TRIGGER DESIGN WITH INDEPENDENT POSITION AND FORCE CONTROL
- FABRICATION AND ASSEMBLY OF ELECTRO-MECHANICAL PARTS OF A STAND-ALONE UNIT FOR PERFORMANCE EVALUATION

FY'86 ACTIVITIES:

- COMPLETION OF FORCE-REFLECTING HAND TRIGGER CONTROL SYSTEM DEVELOPMENT, INTERFACED TO A COMPUTER-SIMULATED AND TO A REAL ROBOT HAND
- PERFORMANCE OF HUMAN FACTORS EXPERIMENTS WITH THE STAND-ALONE FORCE-REFLECTING HAND TRIGGER IN STATIC, DYNAMIC, FREE MOTION AND TRACKING TEST TASKS



Human Stereo Vision Research for Space Teleoperation

The long-range goal of this effort is to design, build and test an automated stereo camera system which adjusts itself for optimal stereo acuity as the work locaton changes in the telerobot's work space. Such an automated system is desirable since a stereo camera system cannot be configured to yield optimal stereo acuity throughout the viewing field without producing optical depth illusions. However, selected regions can be viewed with high stereo acuity without illusions.

The key parameters of a binocular stereo vision system are: zoom (focal length), intercamera distance and intercamera angle. The adjustments of these parameters vary the number of depth planes in a given region. These three adjustments also vary the size of the region of stereo depth. Morevoer, the intercamera angle adjustment controls the amount of the optical stereo depth illusions.

The FY85 accomplishments include:

1. Development and installation of a laboratory system for stereo vision research. All key parameters of interest can be varied in this laboratory system. The cameras are RCA TC2000 b/w vidicon cameras and the stereo viewer is a Honeywell PLZT stereo viewing unit.
2. Completion of preliminary human factors experiments aimed at determining the extent of stereo depth illusions which can be tolerated without decreasing human teleoperator performance. Several human subjects were tested for static stereo depth acuity for various intercamera distances. Analysis of parallel versus varying intercamera angles has also been performed. The analysis of the preliminary results is available in an interim laboratory report.

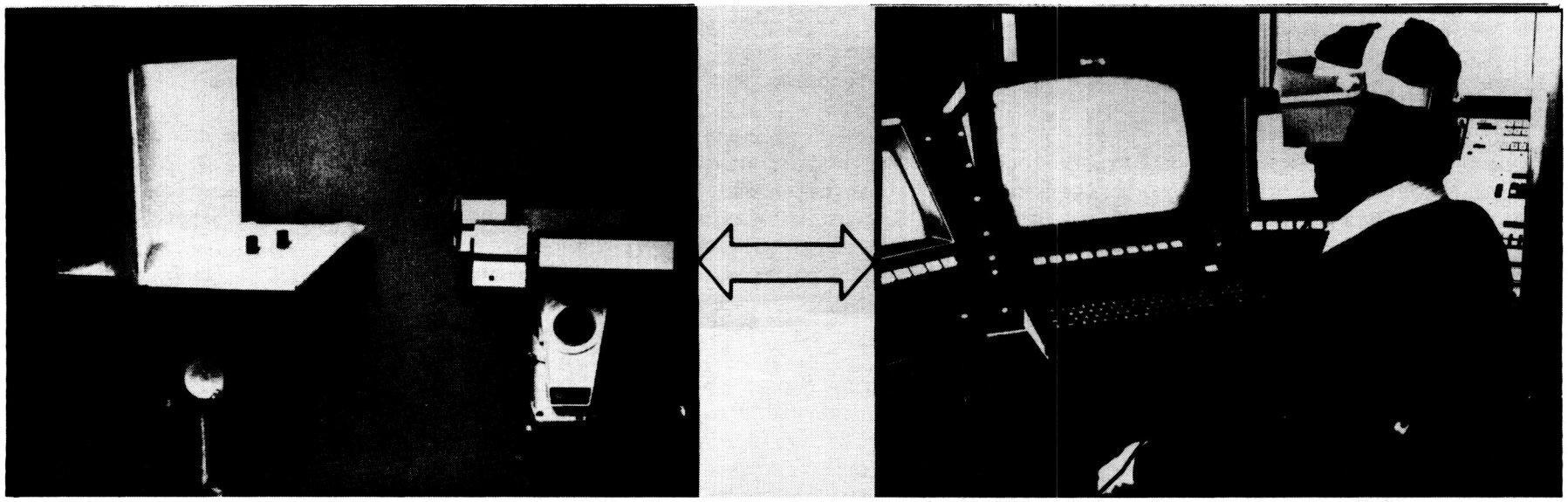
Ongoing and future work includes:

1. Complete experimental testing of static and dynamic stereo depth acuity under various zoom (focal length), intercamera distance and intercamera angle conditions. These experiments will also determine the best camera configurations for various teleoperator tasks.
2. Design, fabrication and testing of an automated stereo camera system which adjusts itself for optimal stereo acuity of the work location.
3. Development of techniques for closed loop camera control linked to teleoperator activity, including controller coordination for moving base cameras.
4. Experimental development and evaluation of a possible combined optical and electronic system which will allow one camera to collect the two views necessary for stereo viewing.

TECHNICAL CONTACT: Antal K. Bejczy, JPL (818) 354-4568
Daniel B. Diner, JPL (818) 354-0351

HUMAN STEREO VISION RESEARCH FOR SPACE TELEOPERATION

REMOTE STEREO TV CAMERA SYSTEM **CONTROL STATION**



OBJECTIVE: DEVELOPMENT AND TESTING OF AN AUTOMATED STEREO VISION CAMERA SYSTEM

FY'85 ACCOMPLISHMENTS:

- DEVELOPMENT OF STEREO VISION LABORATORY RESEARCH SYSTEM
- COMPLETION OF PRELIMINARY EXPERIMENTS FOR PARAMETRIZATION OF BINOCULAR STEREO VISION SYSTEM IN TELEOPERATION ENVIRONMENT

FY'86 ACTIVITIES: EXPERIMENTAL INVESTIGATIONS OF

- EFFECT OF INTERCAMERA DISTANCE AND ANGLE, AND ZOOM (FOCAL LENGTH) ON REGION OF OPTIMAL STEREO DEPTH PERCEPTION
- STEREO OPTICAL ILLUSIONS CAUSED BY PARALLEL VERSUS CONVERGENT INTERCAMERA ANGLES

Neuromuscular Factors Research for Force-Reflecting Manual Control in Zero-G Teleoperation

The long-range objective of this effort is to make full utility of the human operator's manual intelligence in force-reflecting manual control of remote manipulators when the operator is in zero-g condition. Instabilities are anticipated under these conditions and, in fact, have been observed and measured in the JPL teleoperator laboratory using part-simulated zero-g conditions acting on the operator's arm. The part-simulated zero-g condition is accomplished by counterbalancing the weight of the operator's arm against gravity using a moving spring-loaded suspension system.

The source of instabilities in zero-g is the absence of the prestressing of muscles which in g-condition normally occurs to balance the arm's weight in a given posture. As anticipated, the unnatural relaxation of the muscles causes the coupled human-machine teleoperator system to act as an underdamped system. This is particularly evident when the human arm responds to a system-generated, force-reflecting impulse motion. It is hypothesized, however, that the zero-g instabilities can be overcome by appropriate compensation techniques which include: (1) adjustment of control system gains for the hand controller; (2) operator posture strategies; and (3) operator training. In order to develop these compensation techniques, it is first necessary to develop an understanding of the operator's response patterns in force-reflecting manual control in (at least part-simulated) zero-g conditions.

The main FY85 accomplishment is the electromyographic (EMG) data recording of key human neuromuscular activities responding to system-generated, force-reflecting impulse motions in both static and dynamic conditions. Ten test operators had to perform (i) simple elbow extension tasks in the transverse plane and (ii) more complex movement tasks involving both elbow and shoulder extension in a sagital plane with a unidirectional movement to a discrete location. The EMG data recordings were generated in cooperation with researchers from the Physical Education Department of USC, using the force-reflecting hand controller and the part-simulated zero-g facility at the JPL teleoperator laboratory. The experiments were designed to gain a better understanding of the individual muscle contribution to, and the temporal and frequency components of, the measured instabilities.

Ongoing and future work includes: (1) completing the temporal and frequency data analysis of the EMG signals with respect to the kinematics of human arm motion; (2) designing and conducting new experiments based on the findings of previous experiments and using modified hardware and controller capabilities; and (3) development of suitable compensation techniques to overcome the destabilizing effect of weightlessness in force-reflecting manual control of remote manipulators in an Earth orbital control station. Of particular interest is the determination of the time course of adaptation, i.e., the "neuromuscular learning curve", if any, as it relates to zero-g training procedures.

TECHNICAL CONTACTS: Antal K. Bejczy, JPL (818) 354-4568
Daniel B. Diner, JPL (818) 354-0351

NEUROMUSCULAR FACTORS RESEARCH FOR FORCE-REFLECTING MANUAL CONTROL IN ZERO-G TELEOPERATION

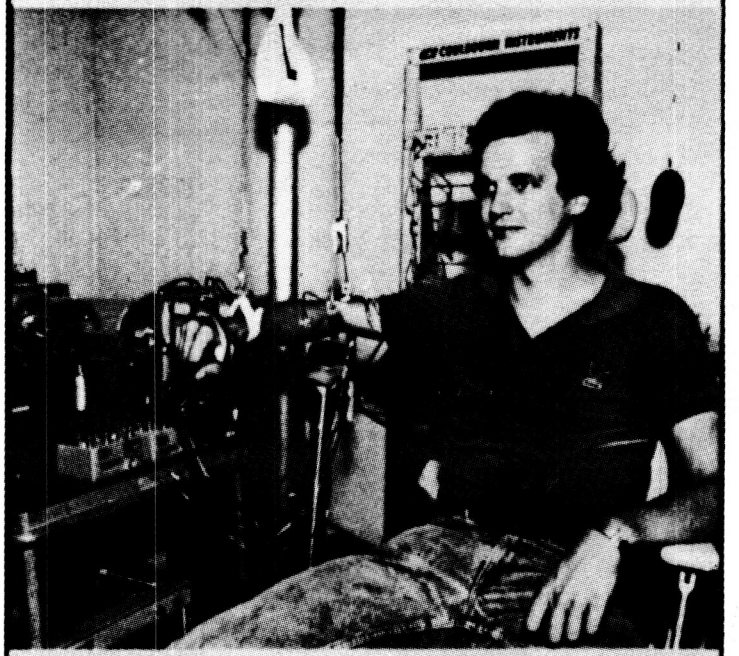
OBJECTIVE: DEVELOPMENT AND TESTING OF ALTERNATIVE CONTROL SYSTEM DESIGNS, OPERATOR CONTROL STRATEGIES AND TRAINING PROCEDURES TO ACCOMMODATE OPERATOR'S NATURAL CONDITIONS AND BEHAVIOR IN FORCE-REFLECTING MANUAL TELEOPERATOR CONTROL IN ZERO-G ENVIRONMENT

FY'85 ACCOMPLISHMENTS: COMPLETION OF PRELIMINARY EXPERIMENTS WITH EMG DATA RECORDING OF KEY MUSCLES ACTIVITES. TEN OPERATORS PERFORMED FORCE-REFLECTING MANUAL CONTROL TESTS IN SIMULATED ZERO-G CONDITION TO GENERATE DATA ON THE OPERATOR'S RESPONSE PATTERNS IN VARYING TASKS

FY'86 ACTIVITIES:

- COMPLETE DATA ANALYSIS OF PRELIMINARY EXPERIMENTS
- DESIGN NEW EXPERIMENTS USING MODIFIED HARDWARE AND CONTROLLER CAPABILITIES
- CONDUCT NEW EXPERIMENTS

OPERATOR'S ARM COUNTERBALANCED AGAINST GRAVITY TO SIMULATE ZERO-G EFFECT ON OPERATOR'S ARM IN FORCE-REFLECTING MANUAL CONTROL



EMG ELECTRODES ARE RECORDING MUSCLE ACTIVITY AT DIFFERENT LOCATIONS ON OPERATOR'S ARM FOR DATA ANALYSIS

Communications Systems

The objective of the Communications Systems Technology Program is to ensure continued U.S. preeminence in future satellite communications technologies by enabling data transmission to and from low earth orbit, geosynchronous orbit, and solar and extraterrestrial missions. This preeminent position can be achieved by maintaining an effective, balanced effort in basic, applied, and demonstration prototype communications technology through work in theory, experimentation and components.

The program is divided among four major research and development (R&D) discipline areas as follows: microwave tube amplifier R&D, antenna R&D, solid state monolithic integrated circuit R&D, and optical communications R&D. Work ranges from basic research in surface science which impacts cathode lifetimes through the study of mechanisms of surface degradations under high voltage and temperature conditions to generic microwave engineering research at X-, Ku-, Ka-, and V- and higher microwave frequency bands. Also included is work on: advanced analog III-V semiconductor devices for eventual implementation into microwave monolithic integrated circuits (MMIC) for employment in adaptive, programmable phased arrays for antenna feeds; the electromagnetic theory and experimentation with large antennas; and the technology necessary to exploit laser technology for optical communications for future low earth, geostationary, and extraterrestrial missions requiring multi-gigabit bandwidths.

PROGRAM MANAGER: Dr. Martin H. Sokoloski
NASA/OAST/RC
Washington, DC 20546
(202) 453-2748

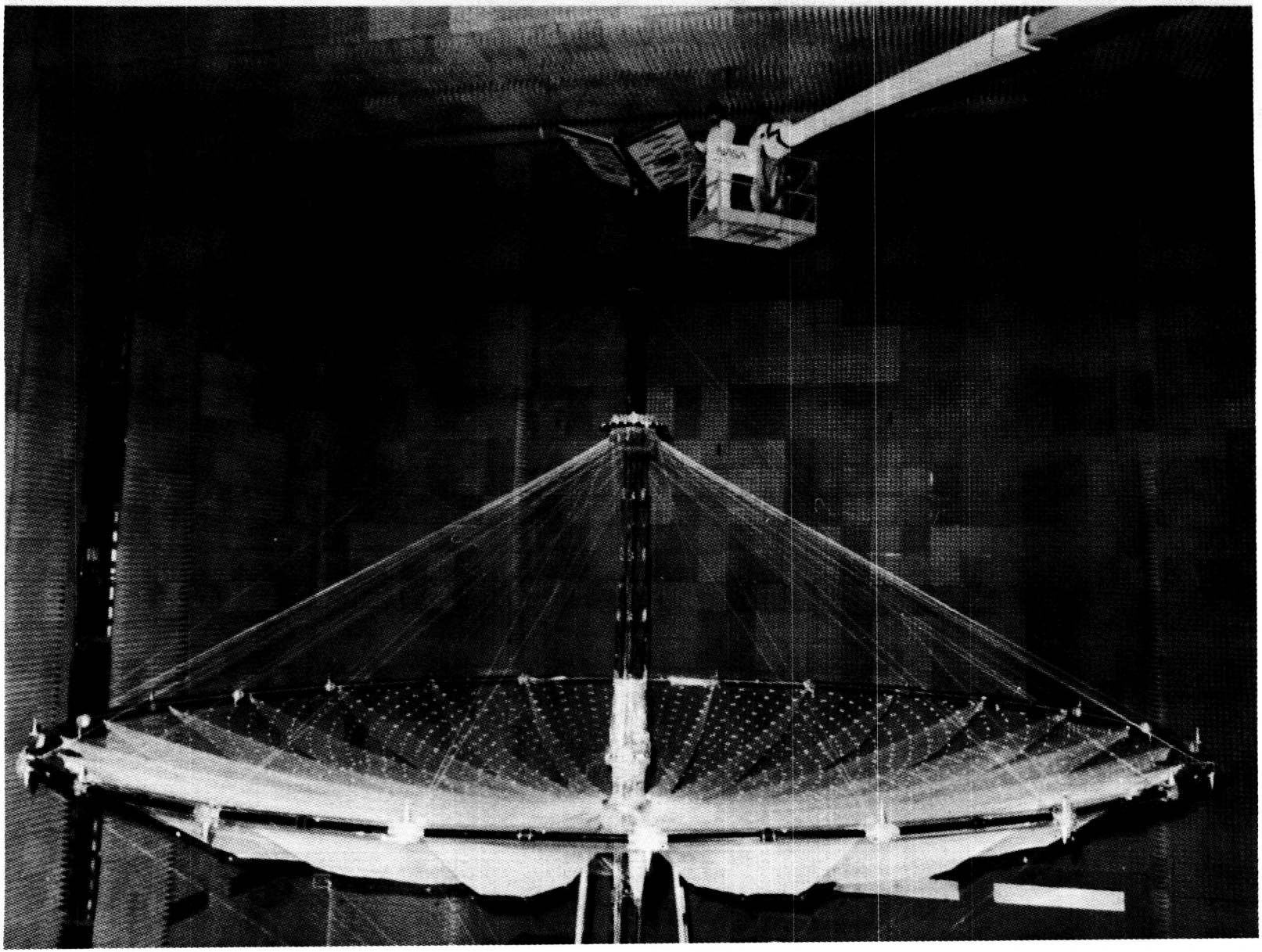
Hoop Column Deployable Antenna System

Recent advances have been made by both NASA and U.S. industry in the technology development of Large Space Antenna Systems. These technological advances now provide new opportunities for the application of large space-based antennas in a variety of science and application experiments in the areas of remote sensing, multiple beam communications, and radio astronomy.

During the past 6 years, NASA-LaRC and the Harris Corporation of Melbourne, Florida have been developing the technology of cable stiffened deployable antenna structures. This effort has now culminated in the development of a 15-meter engineering model (see opposite figure) with final structural and electromagnetic performance measurement results. The test results include deployment kinematics, modal characteristics, reflector surface accuracy characterization during simulated zero gravity conditions, and near field electromagnetic testing. The far field electromagnetic tests of the 15-meter antenna were conducted using the largest near field antenna facility capable of measuring a structure of this size. The experiment and analytical results obtained through the 15-meter antenna program are expected to provide new opportunities for technology development flight experiments in structure, dynamics and control, and electroscience activities.

TECHNICAL CONTACT: Thomas G. Campbell, LaRC (804) 865-3631

HOOP COLUMN DEPLOYABLE ANTENNA SYSTEM



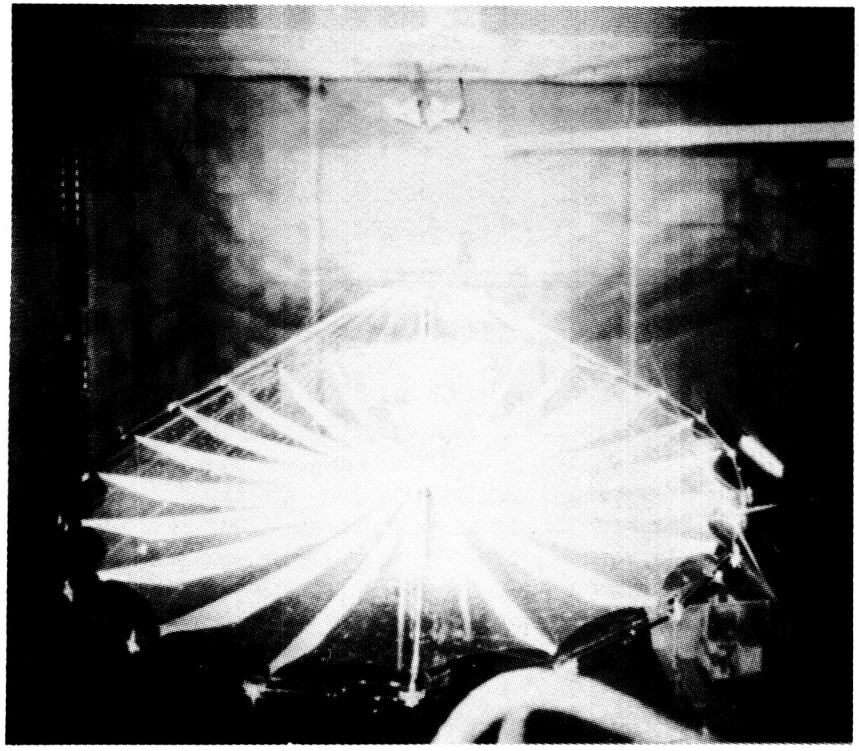
The Development Of An Electromagnetic Analysis Method for Mesh Deployable Antennas

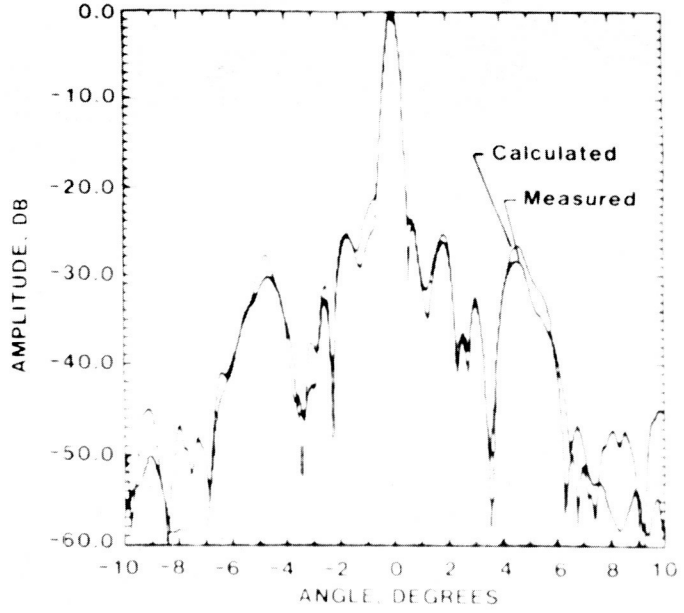
A phase perturbation electromagnetic analysis method for mesh deployable reflector antennas has been developed and verified using the 15-Meter Hoop Column Antenna. The radio frequency performance of the 15-meter mesh deployable antenna was predicted prior to testing the antenna in the Martin Marietta Near Field Facility and significant results have been observed.

The analysis and tests were extended over four frequencies ranging from 2 to 12 GHz. The analysis method verified has the capability for including pillowed surface distortions which generate grating side lobes in the far field radiation pattern from the antenna. A typical example of computed and measured radiation patterns for the 15-meter antenna is shown at 7.73 GHz (see opposite figure).

TECHNICAL CONTACT: Dr. Marion C. Bailey, LaRC (804) 865-3631
Dr. Capers Corkrell, LaRC (804) 865-

THE 15 METER MODEL ELECTROMAGNETIC TESTING VERIFIED PERFORMANCE AND ANALYTICAL METHODS





Near Field Phase Measurements for Improving The Surface Accuracy of a Large Deployable Reflector Antenna

The radio frequency performance of a 15-meter mesh deployable antenna was measured at the Martin Marietta Near Field Test Facility in Denver, Colorado. Immediately after the antenna was deployed, the surface accuracy was determined by using a photogrammetric system and over 800 retroreflector targets mounted on the antenna surface.

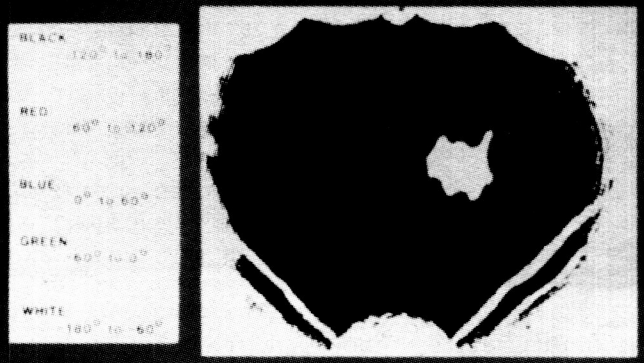
The initial measurement results indicated that a 0.150-in (rms) surface accuracy existed. The decision was made to improve the surface by adjusting 96 rear control cords located behind the mesh reflector and attached to the vertical surface ties. During the adjustment exercise 95 cables were adjusted, leaving one cord unadjusted. A finite element surface analysis program was used to establish the rear cord adjustments. After initiating the near field measurements, it was found that the phase data revealed a major surface distortion—hence, a cord had not been adjusted. The cord was later adjusted; the before and after far field patterns are shown on the opposite figure. A significant improvement in radiation pattern shape and side lobe level can be observed. The utilization of near field aperture measurements for optimizing the surface characteristics of large space structures was thereby demonstrated.

TECHNICAL CONTACT: Dr. M. C. Bailey, LaRC (804) 865-3631

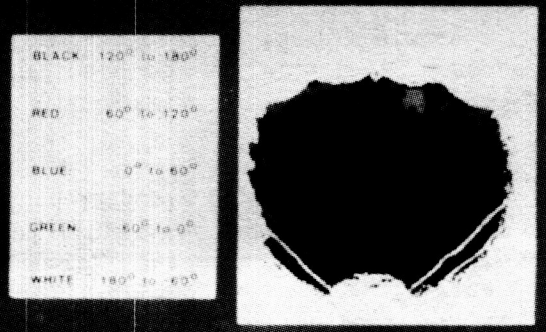
NEAR FIELD MEASUREMENT RESULTS

PHASE DISTRIBUTION PATTERN

BEFORE SURFACE ADJUSTMENT

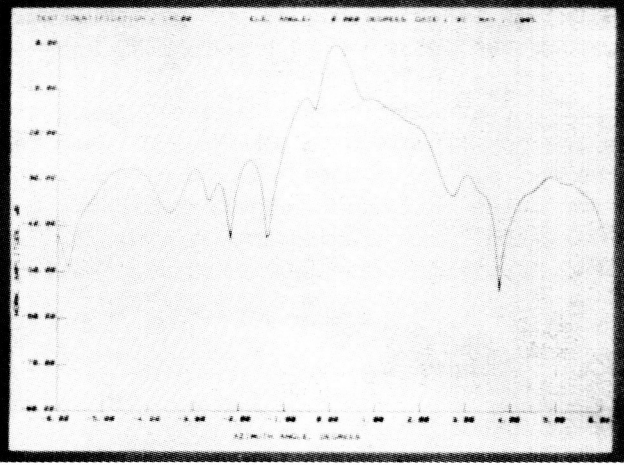


AFTER SURFACE ADJUSTMENT

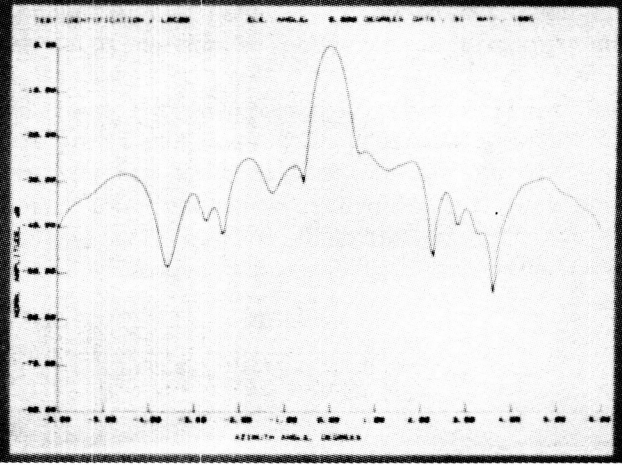


FAR FIELD RADIATION PATTERN

BEFORE SURFACE ADJUSTMENT



AFTER SURFACE ADJUSTMENT



8-Beam Overlapping Cluster Feed for Mobile Satellite Applications

Mobile satellites require antennas having contiguous multiple beams with very low sidelobes for good ground coverage and for frequency reuse. To demonstrate that these requirements can be met with single aperture (as opposed to multiple aperture) offset-fed reflector antennas, an 8-beam overlapping cluster feed has been developed for this purpose. The feed was tested with a 6-m aperture in one of the quadrants of the LaRC/Harris 15-m hoop-column reflector. Test results indicate that contiguous beams with sidelobe levels of about -30 dB or lower can indeed be achieved with single aperture reflector antennas, and that single aperture reflector antennas can be used for mobile satellite applications.

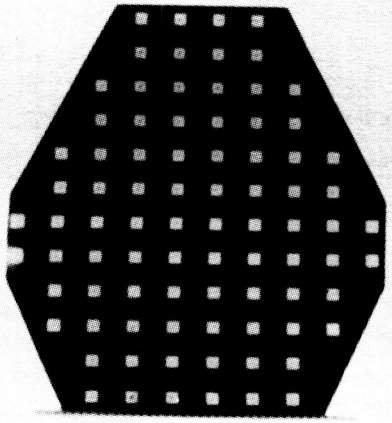
The cluster feed is composed of an array and a beam forming network (BFN) connected together by flexible cables. The radiating aperture and the input terminals of the eight beams are shown in the upper left photographs on the opposite page. By using overlapping 7-element cluster schemes, the 8-beams are produced by 21 feed elements. Each element is made up of 4 circularly polarized microstrip patch radiators, resulting in a total of 84 patches for the entire feed array, as shown. The microstrip patches are used because they are conformal and relatively thin, suitable for deployment when a large size feed is required. The beam forming network (fabricated by Ford Aerospace under a contract from JPL) routes signals into each element with proper phase and amplitude and configures the required overlapping clusters of elements. It has 8 input terminals which also serve as the input terminals of the entire feed, and 21 output terminals which are connected to the 21 feed elements. The interior of the BFN is made up of very intricate networks of Wilkinson type power dividers and combiners, as shown in the lower left photographs. The divider circuits and combiner circuits are separated by a ground plane, and are properly stacked and properly connected by feed-throughs (called "dams"). Although the application is at UHF (or possibly L-band), the feed is designed for S-band operation to satisfy the size limitation of one quadrant of the LaRC/Harris reflector.

The test of the feed with the LaRC/Harris reflector was performed at the Martin Marietta Near-Field Facility. The feed illuminates, in an offset configuration, a 6-m aperture in one of the quadrants of the reflector. Measured near-field data were transformed to far-field patterns via FFT (Fast Fourier Transform). To approximately simulate the case when the feed is used with an isolated single reflector, as the feed is designed for, only the near-field data above and near the 6-m aperture is used to calculate the far-field patterns. Of the four beams measured, the beam locations and inter-beam cross-over levels are as expected. The sidelobes are generally of about -30 dB or lower, except some spurious lobes which have been identified as the residual effects of the feed illumination reflected from the remaining portions of the 15-m reflector, especially from the central column of the reflector. The figure on the right shows a three-dimensional plot of the focal beam (beam on axis) from the 6-m aperture. The relatively high sidelobe on the left side of the beam is a spurious lobe from extraneous reflections. It is anticipated that when the feed is used with a correctly designed isolated single reflector, the spurious lobes will disappear.

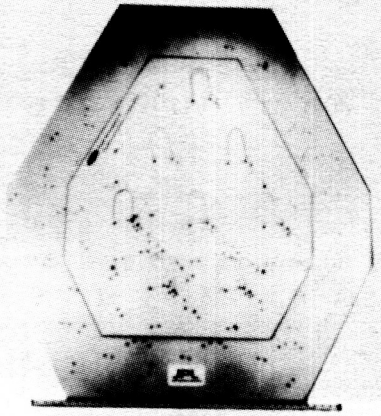
TECHNICAL CONTACT: K. Woo, JPL (818) 354-3835

8-BEAM OVERLAPPING CLUSTER FEED FOR MOBILE SATELLITE APPLICATIONS

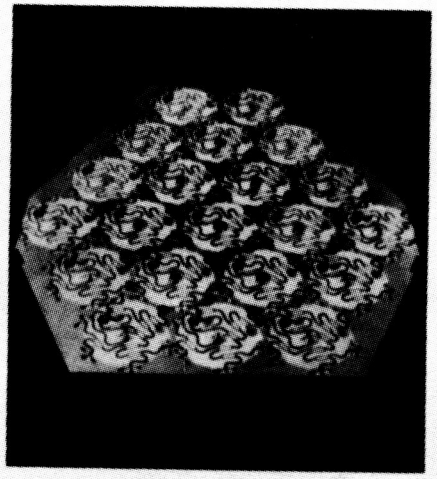
FEED DESIGN



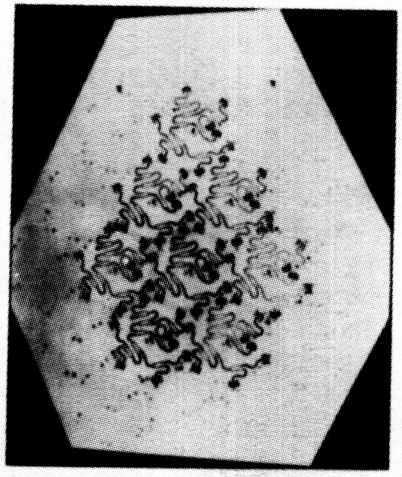
RADIATING APERTURE



INPUT TERMINALS



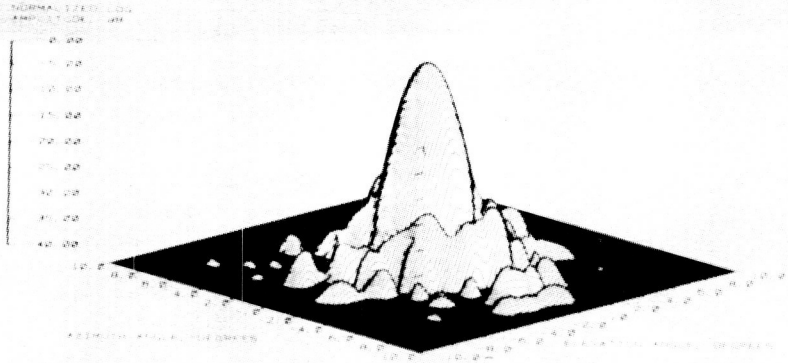
POWER COMBINERS



POWER DIVIDERS

(INTERIOR OF BEAM FORMING NETWORK)

RADIATION CHARACTERISTICS
OF FOCAL BEAM FROM 6-m APERTURE



20 GHz MMIC Transmit Module

The objective of this program is to develop 20 GHz monolithic transmit module technology for advanced communication antenna applications. Developed by Lewis researchers Thomas J. Kascak of Lakewood, Godfrey (Art) Anzic and Denis J. Connolly of North Olmstead, and Rockwell International engineers, the Transmit Module is used to provide RF signal amplification and phase shifting at a frequency of 20 gigahertz. It is of monolithic design in which all module functions are contained on a single 6.4 x 4.8 millimeter semiconductor chip with the smallest circuit feature size of about 40 millionth of an inch. Development of the Transmit Module technology makes possible the production of weight and cost effective advanced phased array antenna systems for future communications satellite systems.

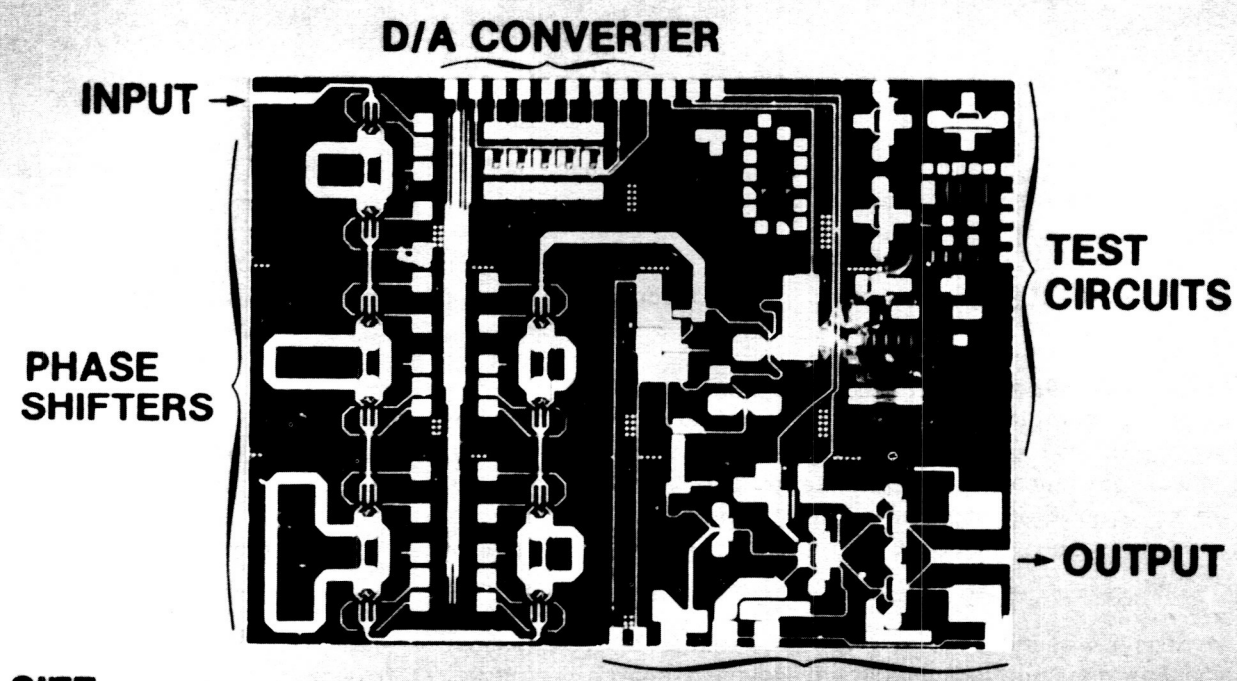
Major goals for the MMIC module are: a 17.7 to 20.2 GHz bandwidth, 200 mW output power, 16 dB gain, 15% efficiency, and a digitally controlled 5-bit phase shifter. The module consists of five switched line phase shifter circuits with control logic, a buffer amplifier to compensate for the phase shifter losses and a power amplifier. The phase shifter incorporates field effect transistors (FETs) as switches and microstrip transmission lines to provide the appropriate phase shift. Submicron (approx. 0.7 micron) gate length FETs are used in the amplifier circuits. Performance measurements include a power output of 21 dBm at 25 dB gain and an RF band response time of 10 nanoseconds at 17.7-20.2 GHz. The use of this MMIC technology will enable the development of weight and cost effective phased array antenna systems.

In February 1984, the program was modified to separate the phase shifting and amplification functions of the transmit module into two modules: a variable phase shift (VPS) module and a constant gain amplifier (CGA) module. This change was made to improve yield and because of system considerations of a LeRC phased array experimental antenna system (EAS) program that is using these modules. Delivery of 100 VPS and 100 CGA modules is planned by March 1986, with an additional 100 of each to be delivered as part of a follow-on effort.

TECHNICAL CONTACT: Thomas J. Kascak, LeRC (216) 433-3508

20 GHz MONOLITHIC TRANSMIT MODULE

DEVELOPED FOR NASA BY ROCKWELL, INTERNATIONAL UNDER CONTRACT NAS3-23247



CHIP SIZE
4.8 mm x 6.4 mm x 0.127 mm

PERFORMANCE
POWER OUTPUT 21 dBm AT 15 dB GAIN
RF BAND 17.7-20.2 GHz RESPONSE TIME 10 NANOSECONDS

Monolithic 30 GHz 5 Bit Phase Shifter

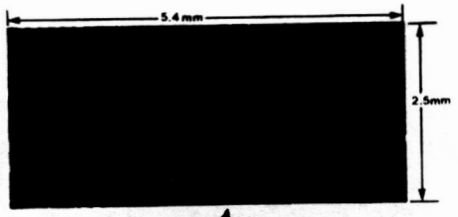
Advanced space communications systems concepts require electrically steerable phased array antennas for transmit and receive applications. These antennas require arrays of several hundred receiving elements, each with controllable phase and gain. The phase and gain of each array member is adjusted to shape the receive beam and "point" the antenna to the proper location. The monolithic microwave integrated circuit (MMIC) approach offers advantages in reliability, reduced parasitics, reproducibility, bandwidth, and system efficiency over conventional hybrid approaches. The monolithic phase shifter demonstrates a 50 times improvement in switching speed and a two order of magnitude reduction in switching power requirements over existing hybrid technology. Monolithic construction of the phase shifter reduces cost and improves the uniformity of the large numbers of modules required in a system. The monolithic phase shifter is an enabling technology for advanced active phased array antenna systems.

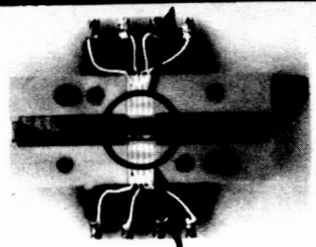
A technology development contract is being performed by Honeywell's Physical Sciences Center to develop and deliver 30 GHz monolithic receive modules and submodules for experimental evaluation. The receive module is made up of four submodules: a low noise amplifier, phase shifter, gain control, and mixer. With the contract about half complete, the phase shifter submodule has been finished. Progress has also been made on the low noise amplifier, gain control and mixer submodules. One hundred phase shifter submodules have been delivered for experimental evaluation. A switched transmission line phase shifter using unbiased FETs was used to achieve the 45^{o}, 90^{o}, and 180^{o} bits, and a loaded line phase shifter was used to cover the 11.25^{o} and 22.5^{o} bits.

The monolithic 30 GHz 5-bit phase shifter (opposite page, upper left) is made on a 2.5 mm x 5.4 mm gallium arsenide substrate. Below this is the phase shifter mounted in a test fixture. The phase shifter is part of the 30 GHz Receive Module, a block diagram of which is in the lower left hand corner. Phase shifters are used in both the transmit and receive antennas of the satellite, shown here in a scanning spot beam mode. Actual measured response of the phase shifter versus frequency is in the upper right hand corner of the chart. Only four of the five bits are displayed for clarity.

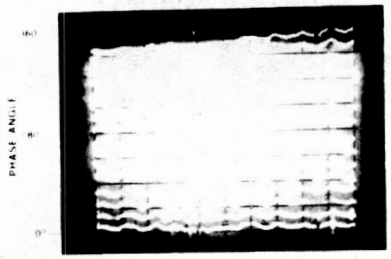
TECHNICAL CONTACT: Denis J. Connolloy, LeRC (216) 433-4475

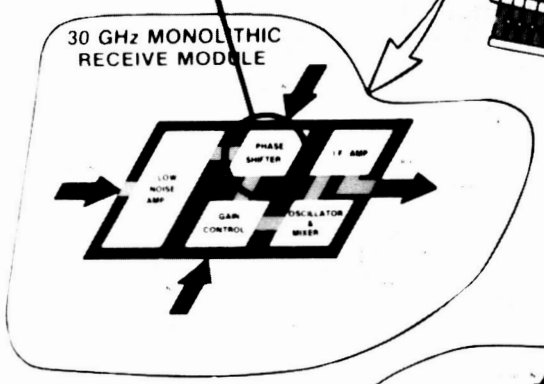
MONOLITHIC 30GHZ 5-BIT PHASE SHIFTER

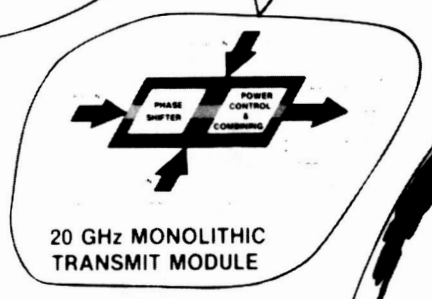


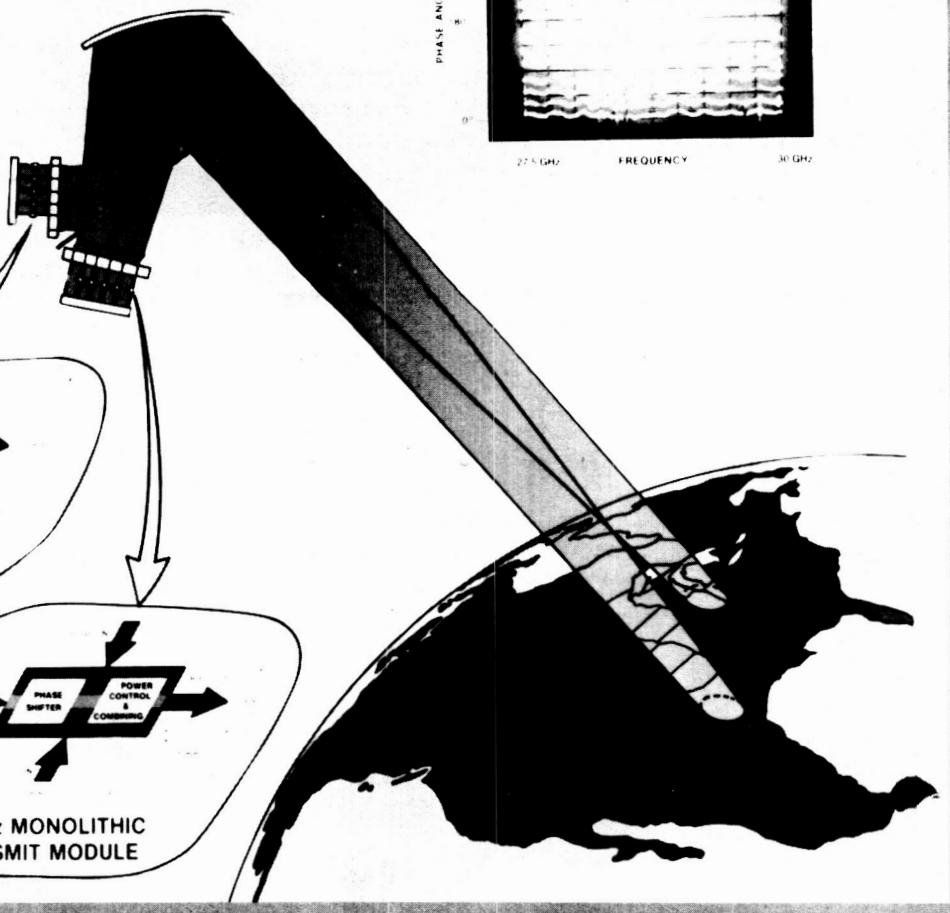


MEASURED RESPONSE









CD-85-1604

60 GHz TWT for Intersatellite Links

A significant breakthrough in broad band high power millimeter wave amplifiers has recently been achieved by Hughes Electron Dynamics Division under contract from NASA Lewis Research Center. This development is a part of the NASA OAST Communications Technology program and has potential applications to future intersatellite communications links for the Tracking and Data Acquisition System and for the Growth Space Station.

The development of high power communications amplifiers at Lewis Research Center began in the late 1960s and resulted in the development of the coupled cavity traveling wave tube (TWT) flown in 1976 on the Communications Technology Satellite (CTS). This 200 watt TWT was operated successfully throughout the operational life of CTS and remains today the highest power microwave amplifier ever flown in space. High power TWTs of this type, however, are inherently narrow bandwidth amplifiers and therefore unsuitable for some proposed space communications applications. Following the launch of CTS, work continued in-house at LeRC on both experimental and computational efforts that eventually indicated the feasibility of a wide band, high power amplifier.

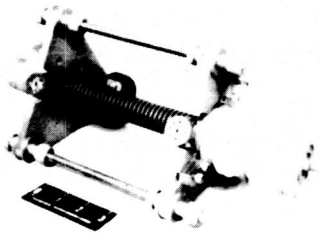
In 1983, a contract was signed with Hughes to develop a coupled cavity TWT for the 59-64 GHz intersatellite band. Because a 10 percent bandwidth was not thought to be readily achievable, the development plan originally proposed to cover only the upper half of the band. The results measured with the first tube indicate that it is capable of operating over a 5 GHz band. However, because this first device was designed only to operate over the upper half of the 59-64 GHz band, its range of operation does not coincide with the band. This TWT, designated 961 H, S/N 101 by Hughes, has achieved a power output of up to 115 watts and an efficiency of 25 percent with a single staged collector. The contract with Hughes will be concluded in FY86 with the fabrication and testing of S/N 102, which will have a four stage collector and an expected efficiency of 40 percent.

The 961 H TWT sets a new standard for high power broad band and millimeter wave amplifiers that could be qualified for use in space. This development has attracted considerable interest in the industry, and a request has been received from TRW to borrow the tube for use in a proposed IR & D program to develop a new class of space-qualified power processors.

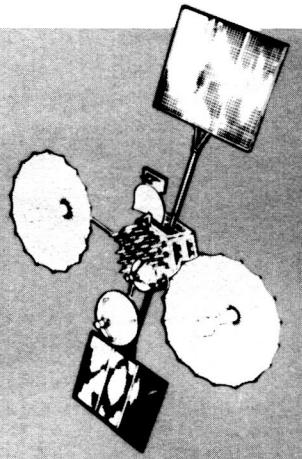
The graph of power as a function of frequency shown on the opposite figure illustrates the performance of the 961 H at both the design voltage of 19.63 kV and at 20 kV. The higher voltage lowers the operating frequency and narrows bandwidth. The notch in the band at 65 GHz can be eliminated by a redesign of the cavity coupling slots.

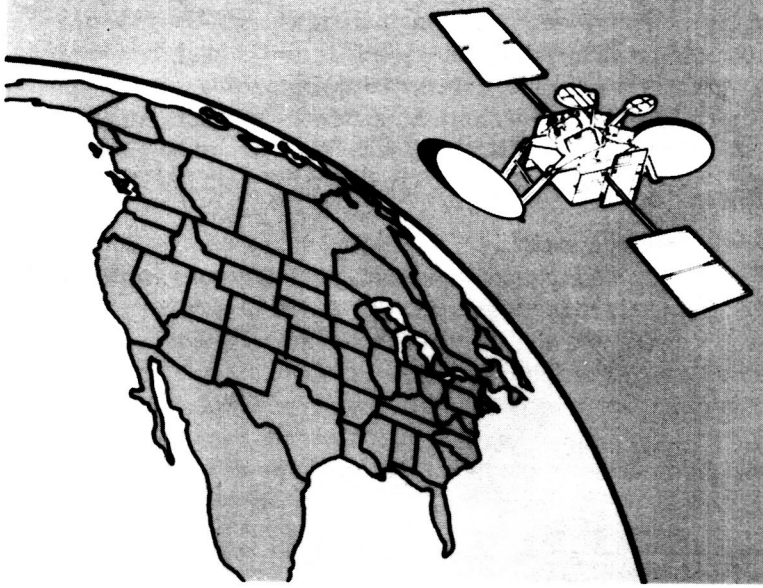
TECHNICAL CONTACT: Jim Dayton, LeRC (216) 433-3508

60 GHz TWT FOR INTERSATELLITE LINKS

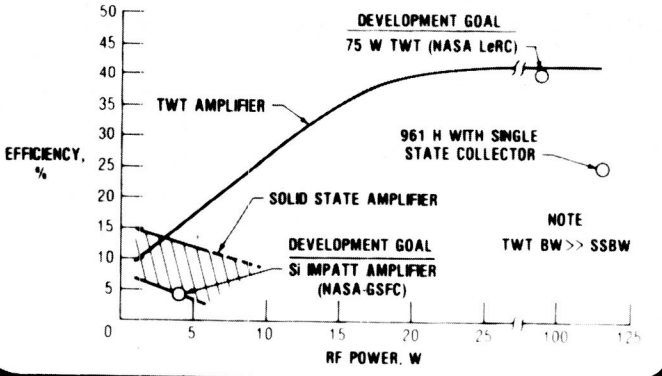


- ONE TUBE COVERS 59-64 GHz BAND
- RUGGED COUPLED CAVITY CIRCUIT
- LIFE TEST PROVEN M CATHODE
- SATURATED POWER 115 WATTS
- EFFICIENCY 25% (WITH SINGLE STAGE COLLECTOR)





RF POWER VS. EFFICIENCY



CD-85-17860

Efficient Solid State Power Amplifier Technology

Deep space communications creates a unique set of requirements over and above those for the near earth environment. These include transmitters with high reliability, long life with high RF and dc efficiencies. Efficiency is an increasingly important concern with outer planet missions, such as being planned under the Mariner Mark II project, since they must use expensive electric power generation equipment (RTGs at $200K/W). Every effort is therefore being made to lower power consumption, including using the lowest transmitter power possible. The requirements for long life and reliability imply the use of solid state RF power amplifiers, but at high frequencies the RF and dc efficiencies of these devices tend to be lower than those of less reliable tube devices such as traveling-wave tube amplifiers (TWTAs). This has created the need for the development of efficient solid state power amplifier technology.

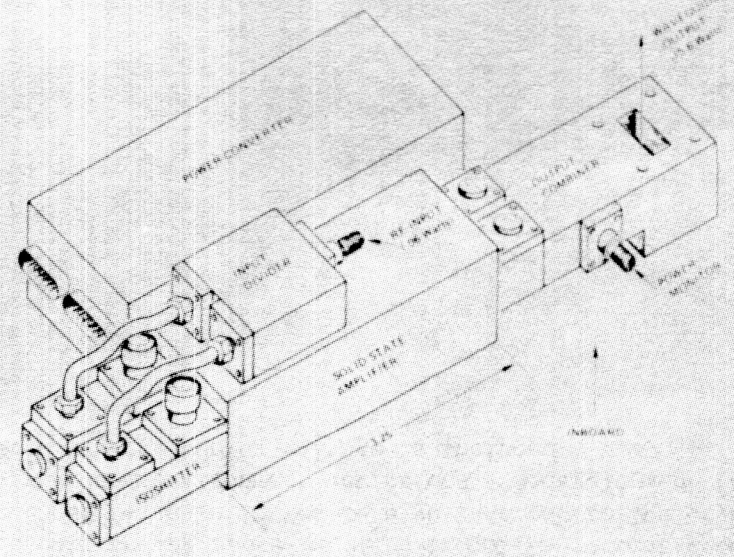
Program efforts are being carried out in two areas: first, the development of more efficient solid state amplifier devices, and second, the development of circuits which make more efficient use of these devices. A program has been undertaken with industry to develop more efficient and reliable GaAs field effect transistors operating at X-band. The result has been the development of devices that have power added efficiencies as high as 40% in some cases. Parallel amplifier stages, with their outputs summed in power combiners, are used to obtain the required output power. Efficient field effect transistor (FET) impedance matching and biasing circuits and low loss power combiners have been developed during this effort and testing is now in progress. During FY86, an engineering model of a 5 watt X-band solid state power amplifier will be developed to meet specifications of the Mariner Mark II Comet Rendezvous/Asteroid Flyby (CRAF) mission (see opposite figure). This development will be co-sponsored by OAST and OSSA.

TECHNICAL CONTACT: A. Lance Riley, JPL (818) 354-0401

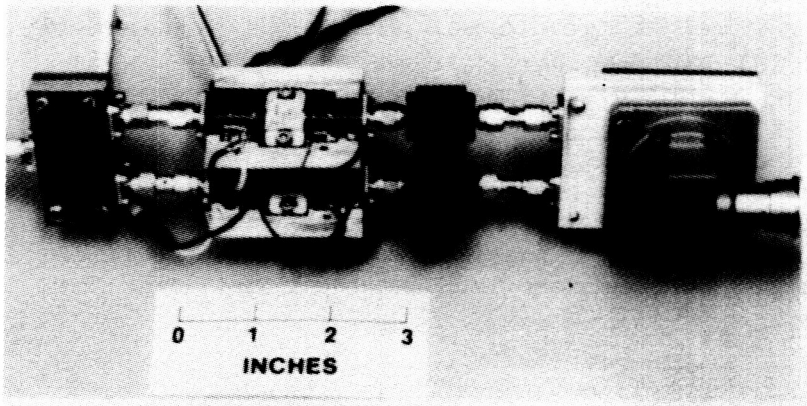
EFFICIENT SOLID STATE POWER AMPLIFIER TECHNOLOGY

APPROACH:

- FET DEVELOPMENT
- RF CIRCUIT DEVELOPMENT
- POWER SUPPLY DEVELOPMENT



5W AMPLIFIER CONCEPT



5W AMPLIFIER BREAD BOARD

PERFORMANCE GOALS:

- 5-10 WATT OUTPUT POWER
- 20 dB GAIN
- > 28% POWER ADDED EFFICIENCY

Surface Acoustic Wave Resonator Oscillator (SAWRO)

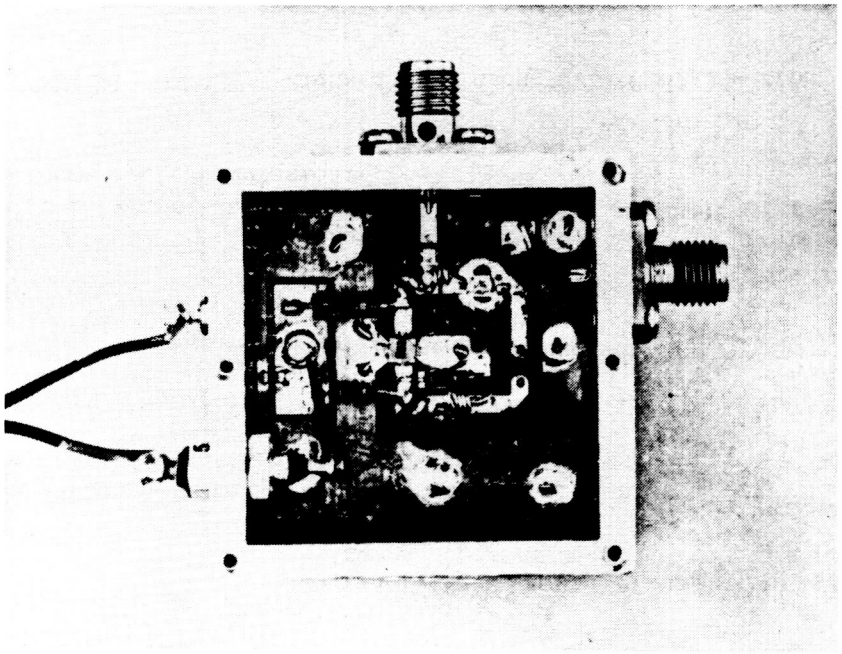
Many spacecraft transponders in use today use frequency multipliers to generate microwave signals from a stable crystal oscillator. Frequency multipliers are generally difficult to align and often have problems with spurious oscillations. As an alternative, a phase locked Surface Acoustic Wave Resonator Oscillator (SAWRO) is being developed for use in a spacecraft transponder. A phase locked loop configuration will improve performance as well as minimize spurious oscillations.

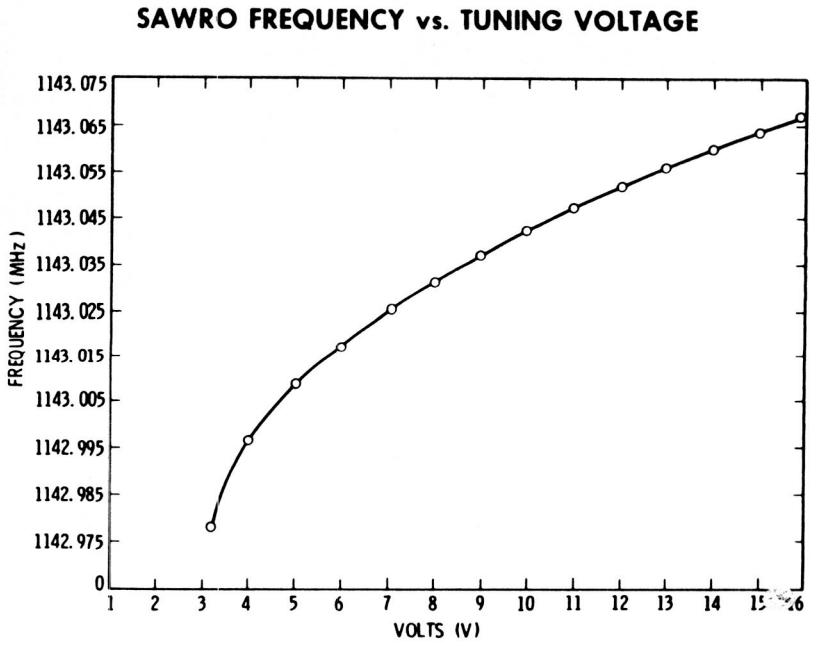
Surface Wave Technology has made it possible to make high quality stable crystal oscillators with frequencies up to L-band. The Surface Acoustic Wave Resonator (SAWR) is a high frequency, high-Q device that exhibits many of the properties of bulk crystal resonators.

The SAWR oscillator being developed is a voltage controlled oscillator operating at 1143 MHz. It uses a bipolar active device with the SAWR in a series feedback configuration. The frequency is controlled by a varactor which changes the phase shift in the feedback network. The oscillator has an electronic tuning range of 100 kHz and is currently being evaluated for use in a phase-locked loop configuration. Since the SAWRO is phase locked to a voltage controlled crystal oscillator, it tracks frequency variation of the uplink received signal and environment variations. A development SAWRO unit is shown on the opposite page; a performance chart showing frequency vs. tuning voltage is included.

TECHNICAL CONTACT: Richard Dickinson, JPL (818) 354-2759

SURFACE ACOUSTIC WAVE RESONATOR OSCILLATOR (SAWRO)





PHASE-LOCKED SAWRO ADVANTAGES OVER FREQUENCY MULTIPLIERS

- EASIER TO DESIGN, FABRICATE AND ALIGN
- REDUCED PHASE VARIATIONS OVER TIME AND ENVIRONMENTAL CONDITIONS
- MINIMIZES SPURIOUS OSCILLATIONS

Digital Filter Processor Chip

The performance of spacecraft transponders can be greatly improved by utilizing digital very large scale integration (VLSI) technology. A digital filter processor, like the one shown in the opposite figure, can be used to replace the analog loop filter in spacecraft transponder applications. The digital filter processor (DFP) has many advantages over an analog filter:

1) More flexibility—loop parameter and filter response can easily be changed.
2) Can perform PLL and AGC loop filtering functions.
3) Eliminates the need for large capacitors associated with long time constraints needed for spacecraft transponders.
4) Improves loop stability by eliminating environmental and time drift.
5) Provides enhanced spacecraft digital interface for telemetry information.

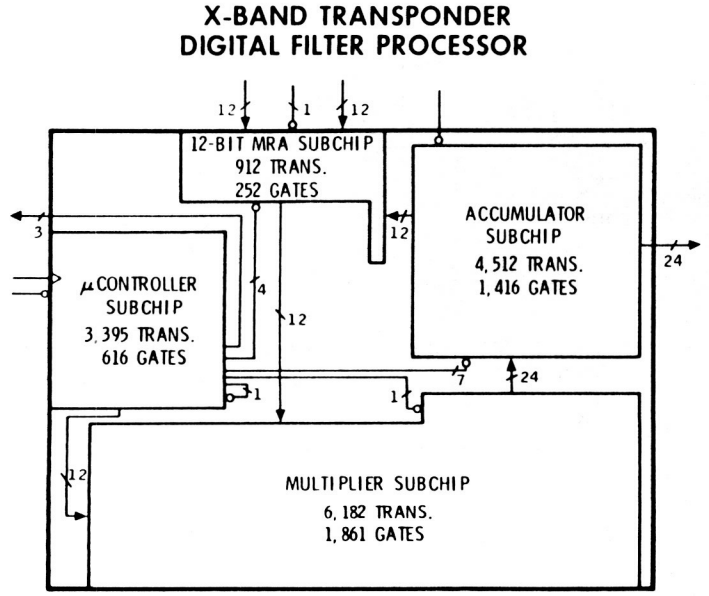
Radiation hardened design techniques were utilized in the chip circuitry. The DFP chip is subdivided into four subchips to enhance functional testability:

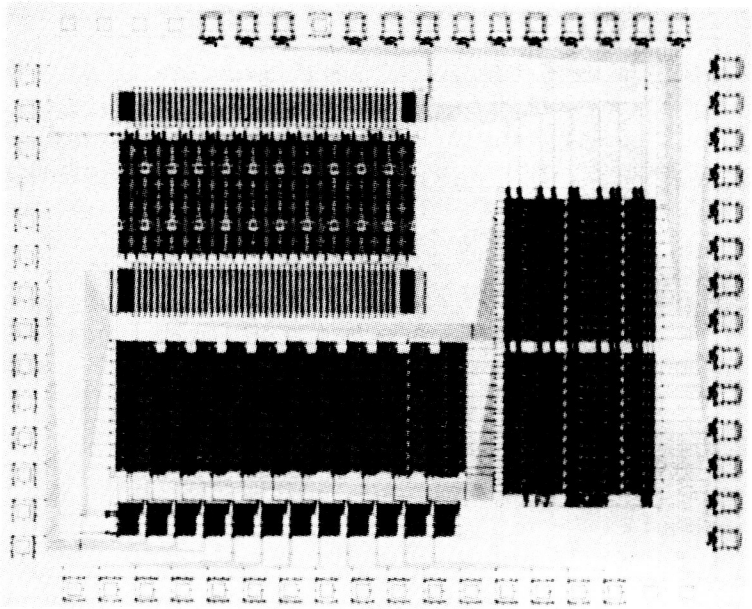
1) Multiplexer Register Array (12 bits)
2) Micro-Controller
3) Accumulator (24 bits)
4) Multiplier (12 bits by 12 bits)

The circuitry in each subchip was designed with a high degree of regularity in order to optimize reliability. The circuitry must be testable to the degree that 99% of the detectable faults are detected using test vectors developed through fault simulation.

TECHNICAL CONTACT: Richard Dickinson, JPL (818) 354-2759

DIGITAL FILTER PROCESSOR CHIP





- USES MODERN VLSI TECHNOLOGY
- DESIGNED AT JPL
- FABRICATED THROUGH THE MOSIS FOUNDARY
- USES CMOS BULK AND CMOS SOS TECHNOLOGY
- CAN BE FABRICATED FOR HI-REL SPACE APPLICATIONS

X-Band Dielectric Resonator Oscillator (DRO)

Past spacecraft transponders have used frequency multiplier chains to generate a microwave signal from a stable low frequency source. In general, multiplier modules are expensive to build, difficult to align, and are often plagued with spurious oscillation problems. As an alternative to a frequency multiplier, a phase-locked dielectric resonator oscillator is being developed for integration into an X-band transponder.

A dielectric resonator oscillator (DRO) is a microwave frequency source which exhibits good temperature stability and has low phase noise. A ring of highly stable, low loss, high dielectric constant material is magnetically coupled to a microstrip transmission line and serves as the high-Q resonant element that controls the frequency of an oscillator circuit. The performance characteristics, structural simplicity, and relatively small size of the DRO make it well suited to spacecraft transponder applications.

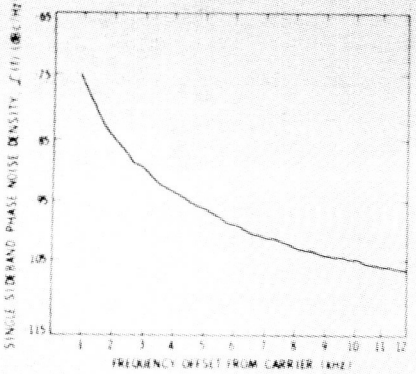
The phase-locked DRO will serve in the X-band transponder as the 1st local oscillator (LO) for the uplink signal receiver as well as be used in the exciter stage for generation of the downlink signal. Because of the stringent frequency stability requirements of a spacecraft transponder, it is important that the DRO has very low phase noise. Furthermore, as the voltage controlled oscillator in a phase-locked loop, the DRO must be electronically tunable over a wide enough range to cover frequency drifts over time and temperature, and ideally the tuning curve is linear to maintain uniform open loop gain. These considerations have been emphasized in the DRO development effort.

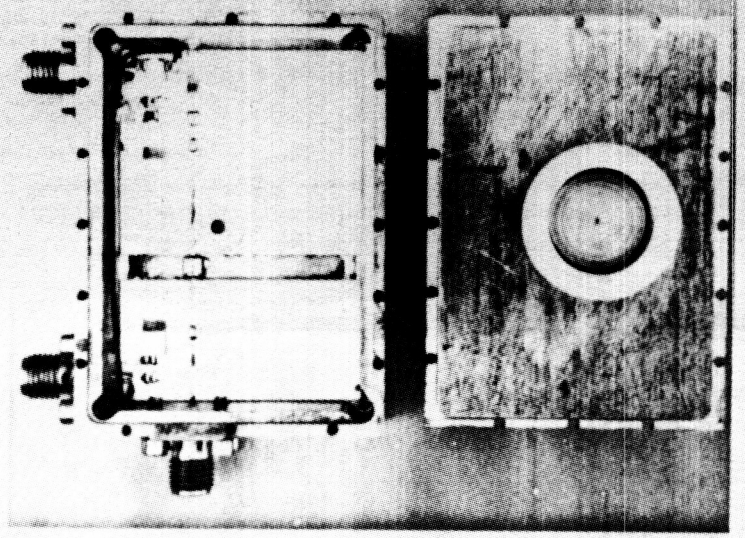
The DRO (shown opposite) operates at 8415 MHz and was designed for minimum phase noise. It has a very low single sideband phase noise density of -75 dBc/Hz at 1 kHz from the carrier. In addition, it provides 1.1 MHz of electronic tuning and exhibits a highly linear tuning response. The unit is mechanically set to the desired center frequency by varying the spacing of a metal plate mounted above the resonator. Temperature compensation is accomplished by using dielectric resonator material with a negative temperature coefficient relative to the rest of the circuit. The unit shown is 2.15 inches long by 1.55 inches wide by 1 inch high. It uses a common collector bipolar transistor for the active device. DRO units using GaAs FETs and different coupling configurations have also been designed and characterized.

TECHNICAL CONTACT: Richard Dickinson, JPL (818) 354-2729

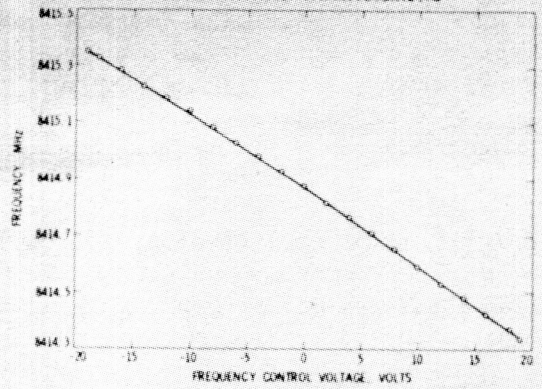
X-BAND DIELECTRIC RESONATOR OSCILLATOR (DRO)

DIELECTRIC RESONATOR OSCILLATOR
PHASE NOISE PERFORMANCE





DIELECTRIC RESONATOR OSCILLATOR
ELECTRONIC TUNING CHARACTERISTIC



DRO APPLICATIONS

- SPACECRAFT TRANSPONDERS
- SATELLITE COMMUNICATION SYSTEMS
- LOCALIZED MICROWAVE LINKS
- RADAR AND GUIDANCE SYSTEMS

PHASE-LOCKED DRO ADVANTAGES OVER FREQUENCY MULTIPLIERS

- SIMPLER TO DESIGN AND LESS COSTLY TO CONSTRUCT
- EASIER TO ALIGN
- REDUCED PHASE VARIATIONS OVER TIME AND TEMPERATURE
- MINIMIZES SPURIOUS OSCILLATION PROBLEMS

Laser Communications

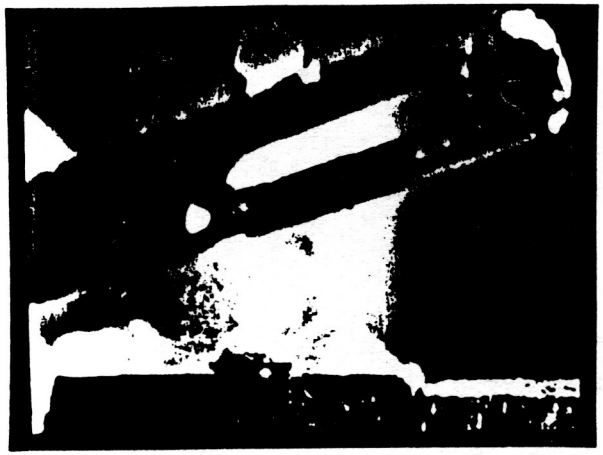
The objective of this research is to develop and demonstrate advanced transmitter and detector components for NASA's intersatellite laser communications systems. The research addresses developing both high power single laser diodes and phase-locked laser diode arrays for communications transmitters, as well as developing very low-noise avalanche photodiode detectors for communications receivers.

High power laser diode-based transmitters with diffraction limited outputs are critical components in free space laser communications links. While present commercially available laser diodes emit from 30 to 50 mW continuous wave (CW), devices with 4 to 8 times more power permit either much higher data rates, or smaller and lighter systems with the same data rate. A joint LaRC-GSFC program at the RCA Sarnoff Labs has been developing Channeled Substrate Planar AlGaAs laser diode which emit in the 800 to 880 nanometer region. Recent work has produced a single laser diode with 150 mW continuous wave output power in a diffraction limited beam. This is the highest diffraction limited power yet reported from a single laser diode. This same device structure has 300 picosecond rise and fall times, which permits 1 Gbit/sec data rates. From recent tests, it appears that selected devices at 100 mW power and good reliability should become available within the next 18 months. Ongoing work on nonabsorbing mirrors should increase this power in reliable devices once their development is complete.

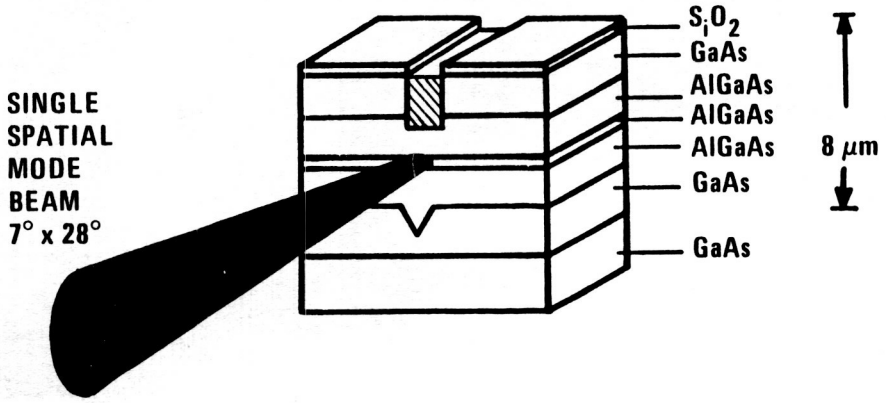
Avalanche photodiodes which have 'stairsteps' in their bandgaps have been proposed as very low-noise detectors for laser communications systems. The GSFC-funded program at the ATT/Bell Labs will take their ongoing research on detectors for fiber optics systems and tailor it to the free space communications region of interest at 800 to 900 nanometers. If this long term effort is successful, detectors with 60-70 percent quantum efficiency and excess noise factors within 2 dB of the quantum limit will result. However, in order to build these advanced devices, extremely precise control of the semiconductor growth process is required. Recent work has successfully demonstrated an early version of this superlattice detector, which had over 200 heterojunction interfaces, had an avalanche gain of 35, and had a 200 picosecond resopnse time.

TECHNICAL CONTACT: Jim Abshire, GSFC (301) 344-8948

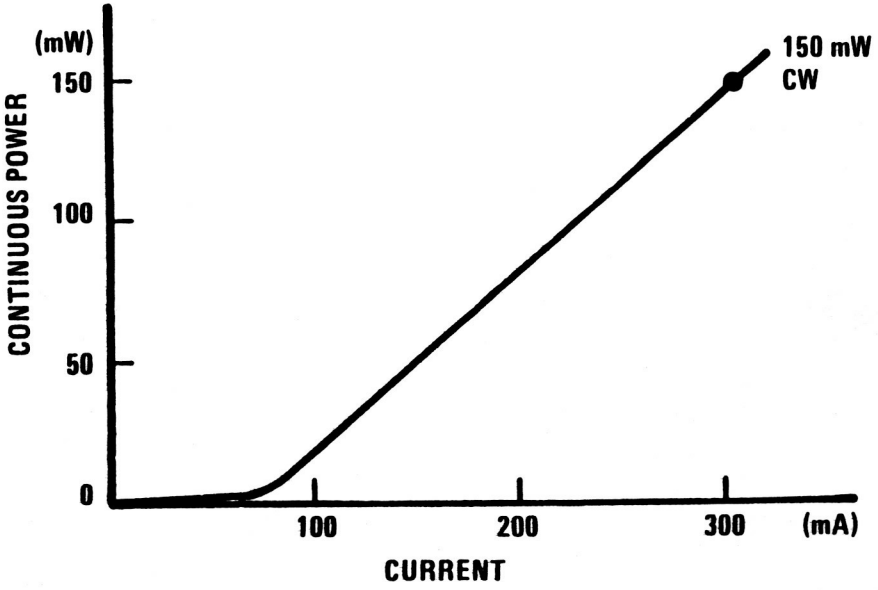
Very High Power
Continuous Wave, Single Mode, Semiconductor Laser
for Optical Space Communication, Fiber Communication and Recording

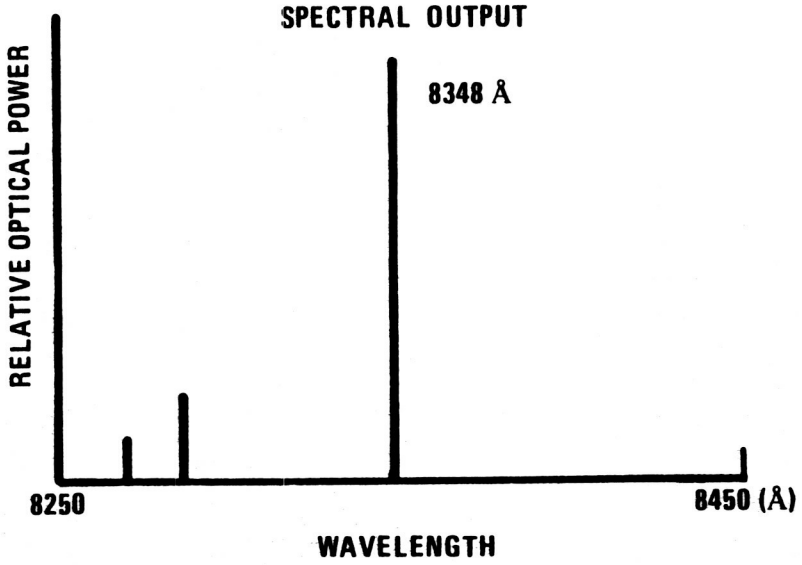


SEMICONDUCTOR LASER AND NEEDLE



CHANNELED SUBSTRATE PLANAR (CSP) LASER STRUCTURE





Computer Sciences

The overall objective of the Computer Sciences Program is to provide advanced concepts, techniques, system architectures, algorithms, and software for space information and computer systems. The program is improving the state of knowledge of fundamental aerospace computing principles and advancing computing technology in space applications such as spacecraft operations and information extraction from data collected by scientific instruments in space. Emphasis is being placed on producing highly reliable software for critical space applications.

The program includes the development of special algorithms and techniques to exploit the computing power provided by parallel processors. The processors include both commercial products such as the Hypercube and Flex machines and NASA developed processors such as the Massively Parallel Processor and the Advanced Digital SAR Processor. Other work is underway to develop and test an expert system that can serve as an assistant to researchers analyzing space derived data.

Research is being conducted in the fundamentals of data base logic. This work has resulted in the development of a common user interface for accessing data from several data bases even when the data bases being accessed have very different structures. This work provides the foundation that will enable NASA space data users access to multiple data bases independent of their physical distribution or structure. This work will reduce the cost of such investigations and enable data base intensive scientific research that would otherwise be unaffordable.

Research is being conducted to improve techniques for producing reliable computing systems. That work is directed at both reducing the number of faults in software and making systems that are tolerant to faults, should they be present. New approaches and methods for software management and engineering have been devised and are now being evaluated under real working conditions.

The Computer Sciences Program is coordinated with DOD software initiative programs which include Software Technology for Adaptable Reliable Systems (STARS), Software Engineering Institute (SEI), and ADA. NASA also participates with DOD on several advisory and technical committees.

PROGRAM MANAGERS: Richard Grumm
NASA/OAST/RC
Washington, DC 20546
(202) 453-2753
Michael McGreevy
NASA/OAST/RC
Washington, DC 20546
(202) 453-2744

Massively Parallel Processor (MPP)

The MPP is an array of 16,384 (128 x 128) processing elements, providing exceptionally high performance for image and large matrix operations. A staging memory serves as a data buffer between the array and the VAX 11/780 that controls the MPP. The staging memory capacity will be upgraded from 2 megabytes to 32 megabytes by February 1986. The MPP is programmable in a parallel version of Pascal and in assembly language.

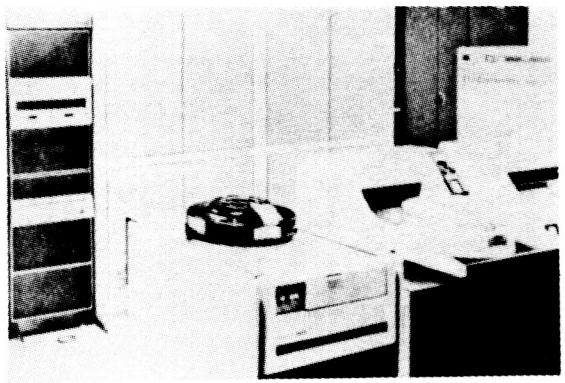
On October 1, 1985, a thirty-five member Working Group began to use the MPP. The Working Group will implement highly sophisticated tasks on the MPP ranging over such interesting computational studies as self-gravitating models for astrophysics and plasma physics, hydrodynamic modeling for oceans, hill slope models for ground water penetration and runoff, ocean and atmospheric circulation models, astrophysical image deblurring, animated graphics for time dependent data presentations, and several exciting neural network models.

The Working Group consists of thirty-five well known principal investigators whose scientifically prestigious projects were selected through an Applications Notice issued in December 1984 by the Office of Space Science and Applications. After one year of using the MPP, the Working Group will produce a report for NASA evaluating performance and potential of the MPP architecture, as well as the system's hardware and software, for applications to Space and Earth Sciences.

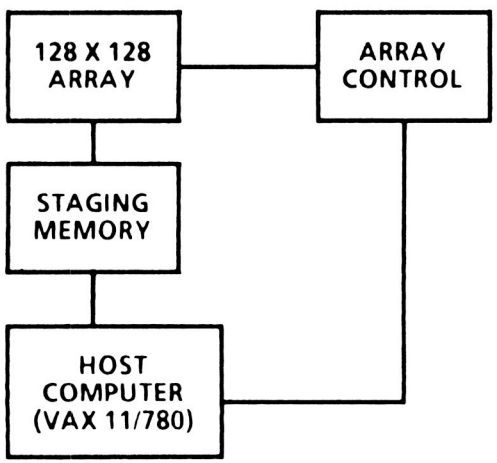
The MPP has recently been used to demonstrate processing of SIR-B and SEASAT synthetic aperture radar (SAR) raw signal data into images while automatically focusing the output images. An MPP algorithm for matching corresponding points in stereo images for use in extraction of elevation information from SIR-B images has also been demonstrated.

TECHNICAL CONTACT: James Fischer, GSFC (301) 344-5184

MASSIVELY PARALLEL PROCESSOR (MPP)



THE MPP AT GODDARD SPACE FLIGHT CENTER



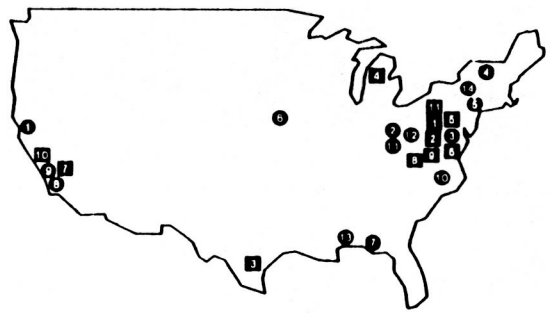
COMPONENTS OF THE MPP SYSTEM

THE MASSIVELY PARALLEL PROCESSOR (MPP)

SYSTEM DEVELOPMENT HIGHLIGHTS DURING FY85

- PARALLEL PASCAL ACCOMPLISHMENTS
  - PERFORMANCE OPTIMIZATION OF MPP TARGETED CODE
  - BETTER UTILIZATION OF ARRAY MEMORY
  - FASTER COMPILATION
  - RUNTIME ERROR DETECTION IN MPP TARGETED CODE
- INITIAL LIBRARY OF GENERIC IMAGE PROCESSING ALGORITHMS

MPP USER SITES



14 UNIVERSITIES
8 RESEARCH LABS
3 NASA CENTERS

APPLICATIONS DEVELOPMENT HIGHLIGHTS DURING FY85

- SYNTHETIC APERTURE RADAR IMAGE GENERATION (SEASAT & SIR-B)
- 4096 ELEMENT FFT
- CONTEXTUAL IMAGE CLASSIFIER
- TEXTURE ANALYSIS ALGORITHMS
- CONNECTED REGION LABELING
- STEREO MATCHING ALGORITHM
- RADIOMETRY CONSERVING GEOMETRIC REGISTRATION
- LARGE NUMBER FACTORING

Software Management Environment

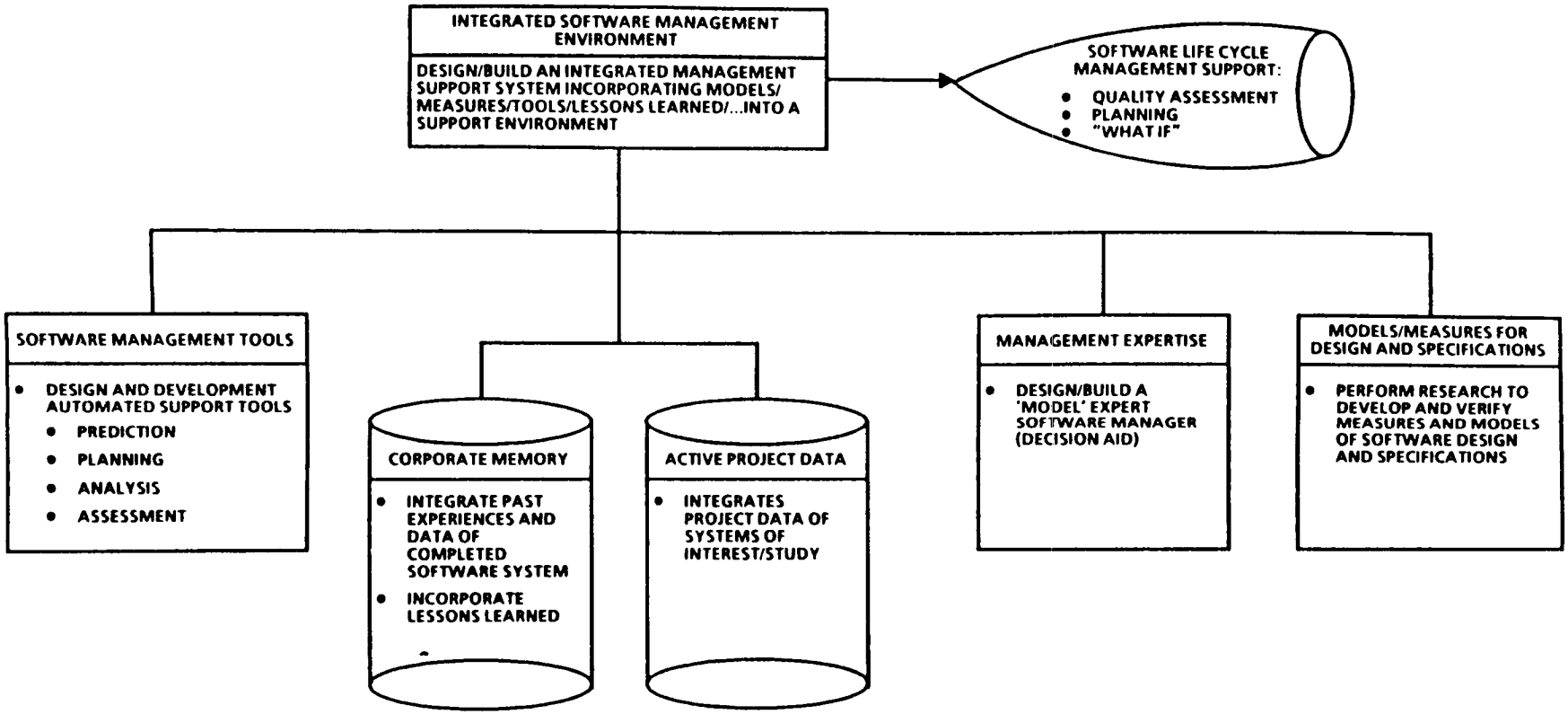
The objective of this effort is to perform research into key areas of software management leading to the development of an operational software system called the software management environment. This software management environment will consist of an integrated set of tools and software measures which will support the improved management and acquisition of large, complex software systems. Typical tools include rapid prototyping aids and quality assessment aids, as well as cost and scheduling predictors.

Work in FY85 was completed in several areas of research (see opposite figure). An extended set of software management rules was defined and incorporated into the Dynamic Management Information Tool (DYNAMITE); a demonstration version of the tool was available in October, 1985. A Structural Analysis Program (STRAP) and an upgraded rapid prototyping aid (MMAS) are also designed as part of the overall environment. The environment executive, which is designed to integrate the set of management aids, as well as numerous software measures have also been designed with implementation scheduled to begin during the upcoming year.

Several reports describing characteristics and application of measures for software specifications and design were completed during the past year. One of these reports describes an approach to recasting software specifications into a form which enables identification of inconsistencies, or incompleteness, and it also provides a mechanism for determining complexity and the probable effort required to implement. Additional flight dynamics projects are now utilizing this approach, called the Composite Specification Model.

TECHNICAL CONTACT: Frank McGarry, GSFC (301) 344-6846

SOFTWARE MANAGEMENT ENVIRONMENT FOR NASA



FY 85 ACCOMPLISHMENTS

1. FUNCTIONAL DESIGN OF INTEGRATED ENVIRONMENT COMPLETED
2. PROTOTYPE VERSION OF 'DYNAMITE' COMPLETED (MANAGEMENT ANALYSIS AID)
3. DESIGN OF 'STRUCTURAL ANALYSIS PROGRAM' (DESIGN AID) COMPLETED
4. FIRST ASSESSMENT OF CSM (SOFTWARE SPECIFICATION MEASURES) COMPLETED
5. ASSESSMENT OF CLASS OF DESIGN MEASURES COMPLETED (STRENGTH/COUPLING)

Software Life Cycle Model

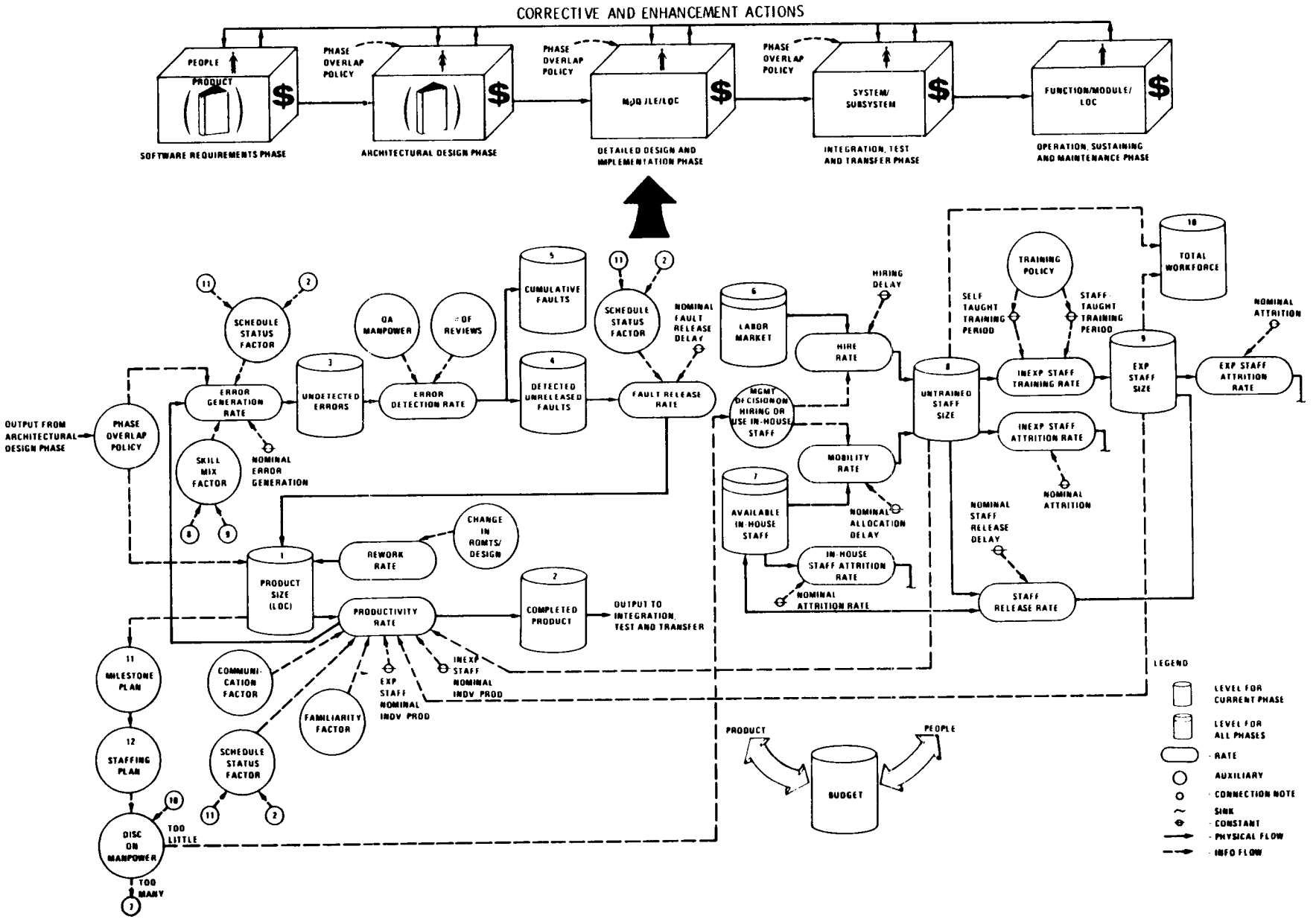
The process whereby software is produced and sustained is both complex and dynamic. Viewed as a system, the software process or life cycle is composed of numerous components (e.g., products, staff levels, budgets, schedule, delays, management styles, and methodologies) that are highly interrelated. Further, these potentially nonlinear relationships vary with time across the often parallel life cycle phases. Nevertheless, good software management must address these complexities with a largely intuitive approach.

The software life cycle, as a dynamic system, is not fully understood, and schedule and budget overruns persist. The Space Station era, however, demands more exacting functionality with more constrained resources. A mechanism is needed whereby the software life cycle process can be scientifically analyzed, and software managers can be reliably supported in planning, contingency analysis, and control.

Under an earlier subelement, a Software Life Cycle Simulation (SLICS) model that simulates the JPL software process was developed. This new subelement, Software System Research, is a cooperative effort with the Johnson Space Center to develop and validate a model of a Space Station Software Life Cycle. SLICS-S will be tailored to Space Station using relevant detailed data from Shuttle and conceptualizations of the Space Station environment. Validation will be effected using behavioral Shuttle data and management heuristics. The validated model will then be used in FY86 to support planning for the Space Station Development Environment (SDE). In future years, the model will support additional Space Station applications.

TECHNICAL CONTACTS: Merle McKenzie, JPL (818) 354-2577
Chi Y. Lin, JPL (818) 354-4784

SIMULATION MODEL OF THE SOFTWARE LIFE CYCLE



Development of a Theoretical Basis for the Assessment of Software Redundancy

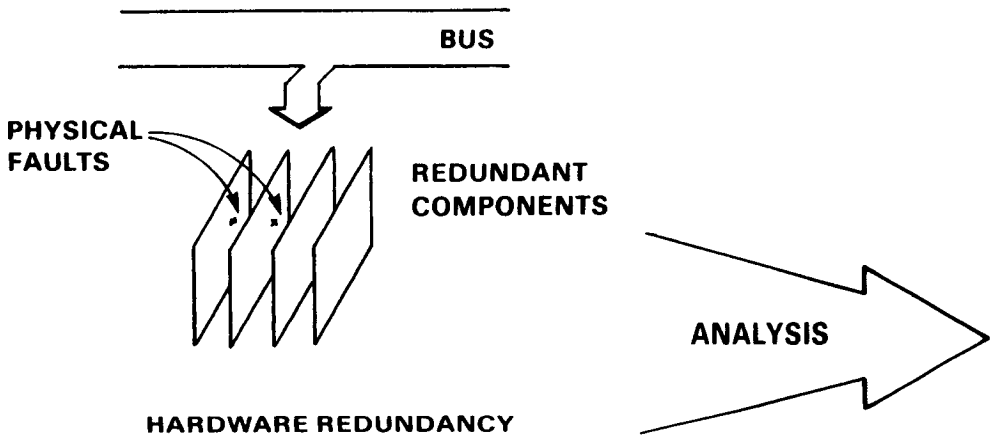
Hardware redundancy has long been established as an effective method for increasing the reliability of physical systems. Dissimilar redundancy applied to software (known as fault-tolerant software), however, is a relatively new and untested technology largely motivated by the need for high reliability in critical software systems, such as avionics, or in industrial process control where software failures may result in loss of life or system control. Under the assumption that software errors will be independent in the independently-designed replicate software codes, existing models project large gains in reliability (or equivalently, large decreases in the system failure probability) as the level of redundancy increases. However, recent empirical evidence suggests that joint errors among software components, referred to as coincident errors, may not be independent. Existing models do not provide an adequate theoretical basis for analyzing the effects of these coincident errors on fault-tolerant software.

A theoretical framework was developed for studying the failure probability of multi-version software systems where the component versions give rise to coincident errors (see opposite figure). The theory suggests a model which uses directly observable quantities associated with the experimental process of testing replicate software components and, thus, provides a basis for empirically evaluating the strategy of software redundancy. Moreover, the model permits an analytical study of the effects of coincident errors and provides new insight into the reliability gains that can be achieved with software redundancy. A study was completed which gives results fundamental to the understanding of the effects of coincident errors on multi-version, fault-tolerant software. A major result of the study was the discovery that the assumption of independent software design errors can lead to poor predictions of reliability when using existing models which assume independent errors. It is apparent that, however, even in the presence of coincident design faults, software redundancy can be an acceptable strategy for improving softare reliability though the cost, in terms of the level of redundancy required to achieve a given level of reliability, may be higher than anticipated. Above all, a policy of attempting to constrain software costs by trading-off software validation for increased levels of redundancy in the belief that arbitrarily high levels of reliability can be achieved does not appear to be warranted until reliability gains can be quantified with empirical data. The current research effort is designed to obtain empirical data from Grantees and Contractors, which will then be used with the new model to further develop and validate software redundancy techniques.

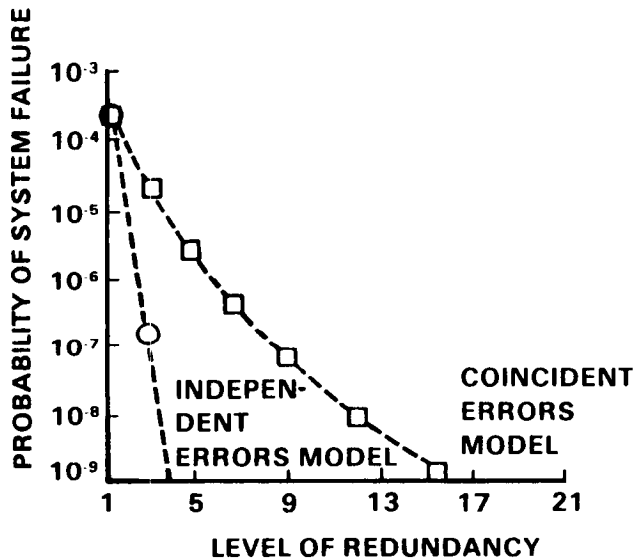
The results of this study have been published in NASA TM-86369.

TECHNICAL CONTACT: Dave E. Eckhardt, Jr., LaRC (804) 865-3681

DEVELOPMENT OF A THEORETICAL BASIS FOR THE ASSESSMENT OF SOFTWARE REDUNDANCY



ANALYSIS



- SOFTWARE DESIGN FAULTS INDEPENDENT?
- EQUIVALENT RELIABILITY GAINS?
- DATA SUGGESTS COINCIDENT DESIGN ERRORS
- THEORY DEVELOPED
- FUNDAMENTAL UNDERSTANDING OF EFFECTS OF COINCIDENT ERRORS
- EMPIRICAL DATA REQUIRED

RIACS: Research Institute for Advanced Computer Science

RIACS was established at the Ames Research Center in June 1983. It is privately operated by the Universities Space Research Association (USRA) under contract to NASA. Its purposes are to help build a pool of top computer science talent at Ames, to conduct a research program, to attract top computer science faculty and industrial researchers on leave, and to establish links with universities and industry.

The diagram at the left (opposite page) shows the components of the RIACS computing laboratory. The Sequent Balance 8000 computer has 12 processors, 16 million bytes of main memory, and runs Berkeley 4.2 UNIX. Twenty active users are connected to this system; most have BitGraph terminals. An image-scanner is connected to a Sequent port. The MacIntosh system's printer port is connected to a Sequent port linked to a process that generates Imagewriter output on the QMS laserprinter. The 32-node Intel iPSC hypercube is connected to a small computer, the 310 Hostmaster, running a UNIX variant called Xenix. The Ridge 32 computer is a document server that runs "troff" jobs and drives the QMS laserprinter. The DEC VAX-11/730 is a communications gateway, linking the facility to MILNET, phone lines, and the UUCP net. The Silicon Graphics IRIS workstation is part of a project to port UNIX utilities into the workstations used by the Numerical Aerodynamic Simulator (NAS) facility at ARC. "HJA" are the initials of a VAX-11/780 in the Thermosciences Division of Ames. By linking these dissimilar units to a common Ethernet, the RIACS laboratory has demonstrated its ability to set up and maintain a heterogeneous computing environment.

The RIACS research program focuses on projects in concurrent processing and autonomous systems, two areas of computer science of top priority to NASA. The goal is advanced software systems that support scientific research in many disciplines, from problem formulation to results dissemination. The concurrent processing research is centered on a testbed of multiprocessors, initially the Sequent and the Intel hypercube, coupled with a program to form interdisciplinary teams to study algorithms in disciplines where computing power in excess of 1 GFLOPS is required. Initial software tools for this effort include Concurrent C and a Graphical Shell. Concurrent C is an extension of the C language allowing programming of parallel tasks. The Graphical Shell is an extension of the UNIX shell that permits computations consisting of distributed processes to be expressed as dataflow graphs drawn by the user. Because the processes can be on different machines, the system will easily support workstation-supercomputer computations. The diagram at the right illustrates a possible future version of the Graphical Shell, showing a large problem in aircraft flow simulation expressed as a computation that spans several machines in the network.

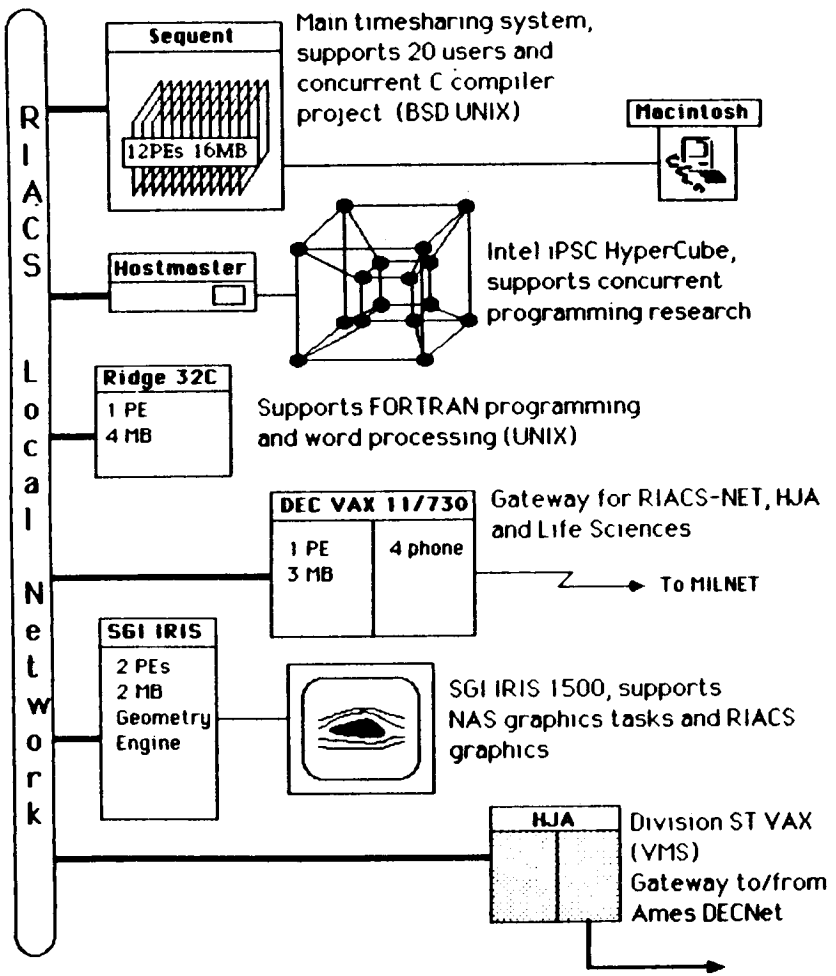
The autonomous systems research is centered on a model of sparse, distributed memory capable of accessing stored patterns when presented with partial patterns. The patterns can be very large, 1000 bits in the prototype. By 1986, a simulator of the memory will be operational and in use for robotics and human factors research. Breadboard models of the memory device will also be developed in cooperation with Stanford.

TECHNICAL CONTACT: Peter J. Denning, ARC (415) 694-6363

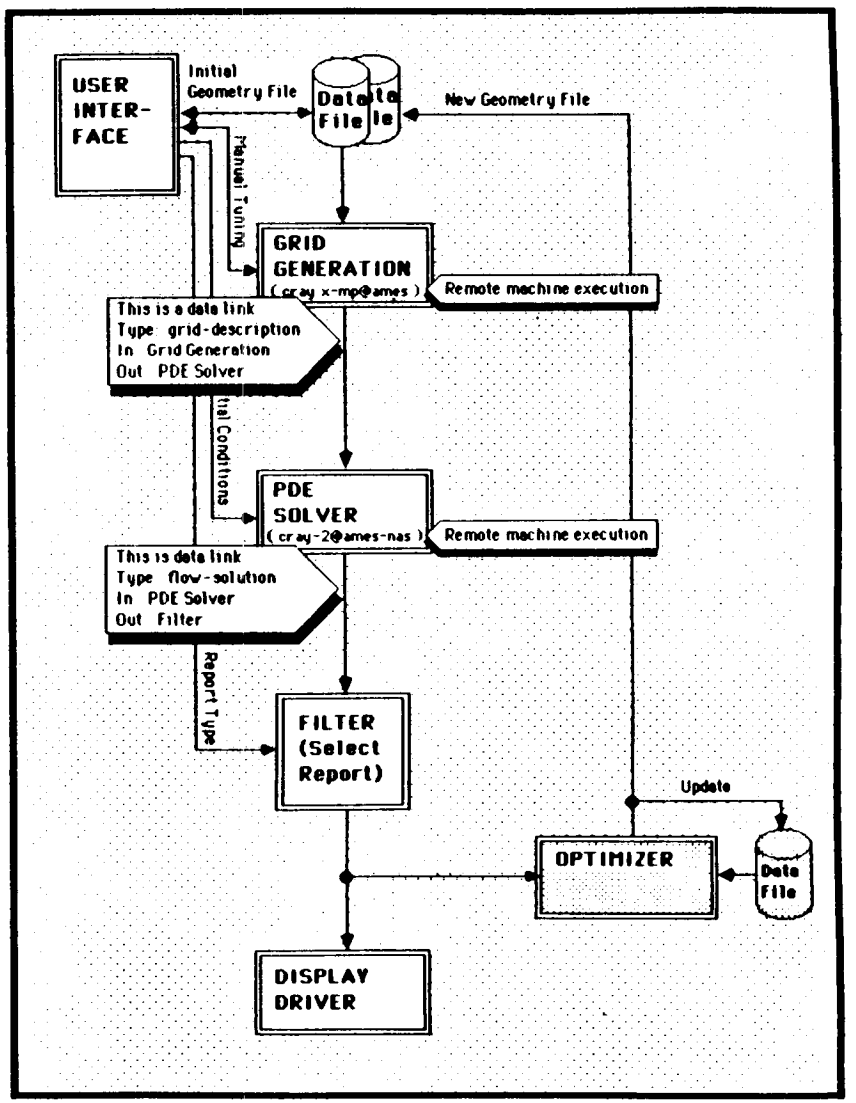
RESEARCH INSTITUTE FOR ADVANCED COMPUTER SCIENCE (RIACS)

RIACS Computing Facility

Hetergeneous Network



EXAMPLE ULTRA-HIGH LEVEL USER INTERFACE



CASIS: Center for Aeronautics and Space Information Sciences

The Center for Aeronautics and Space Information Sciences (CASIS) was formed at Stanford University in January 1983. Under a block grant from NASA's Office of Aeronautics and Space Technology, CASIS conducts a variety of programs of basic computer science, computer systems, and information systems research related to scientific and engineering information management.

Areas of emphasis include satellite telecommunications, local area networks, VLSI signal processors, concurrency studies, and remote space science operations. Telecommunication research is centered on reducing the cost and increasing the performance of circuits and systems. Local area network research is focused on fiber optic network topology prototypes, access protocols, and VLSI network interfaces, as well as distributed graphics software tools and user interface architectures. Experimental special purpose VLSI signal processors are being developed based on research into new algorithms and architectures. To support this effort, VLSI hardware description and emulation tools are also being investigated. Concurrency studies are centered on performance prediction and reliability. Remote space science operations research is concerned with telecommunication requirements, telescience workstation requirements, and distributed payload operations.

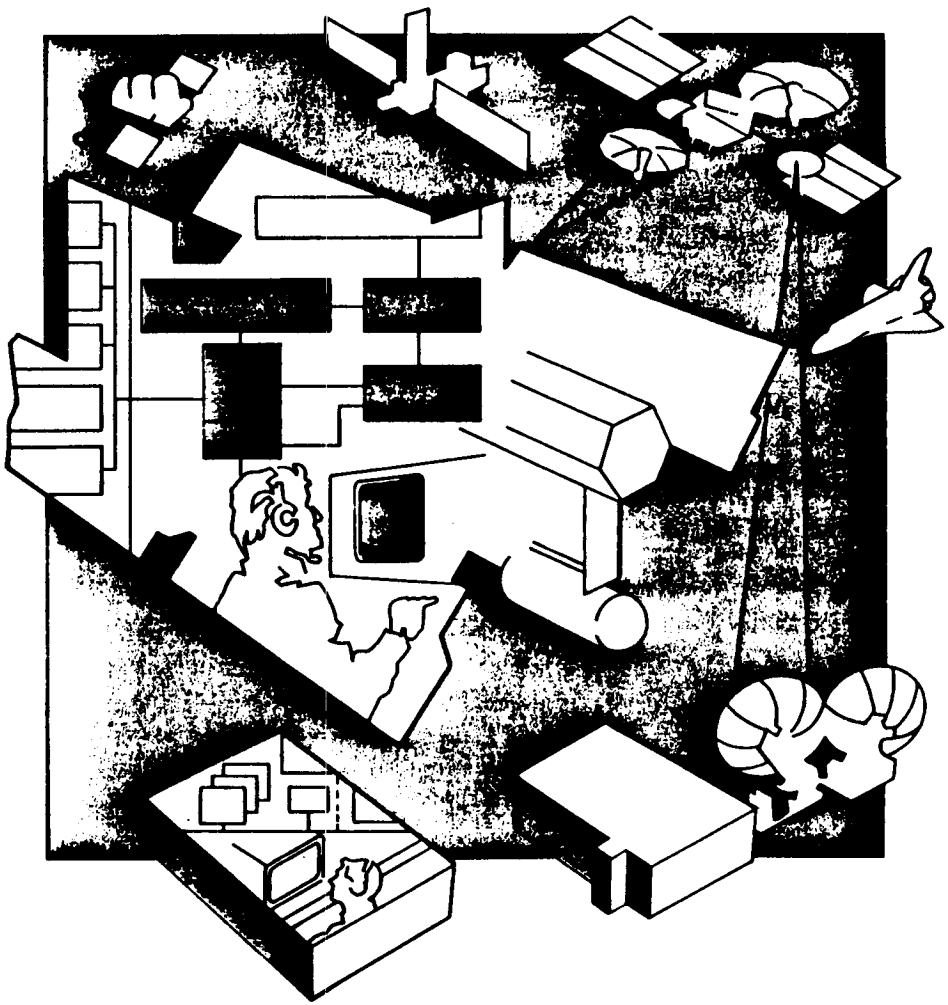
In 1985, CASIS researchers initiated the first link in a low cost, high performance satellite network to link Stanford and the Spacelab orbital laboratory. Basic research for the system was conducted under CASIS and then transferred to NASA's Office of Space Tracking and Data Systems for development. The satellite link will consist of two channels, a bi-directional 1200 baud administrative link and a 7M baud data receiver at Stanford. Currently, transmission tests are being conducted. Early in 1986, there will be a test using pre-recorded Spacelab data. Late in 1986, a flight experiment is scheduled which will link Stanford directly to a Shuttle payload.

TECHNICAL CONTACT: Prof. Peter M. Banks (415) 497-2848

CENTER FOR AERONAUTICS AND SPACE INFORMATION SCIENCES (CASIS)

STANFORD UNIVERSITY, STANFORD, CALIFORNIA

- FUNDAMENTAL RESEARCH OF INTEREST TO NASA
- FOSTERS NASA/UNIVERSITY COOPERATION AND INTERCHANGE
- ENCOURAGES EXPERTISE IN SUPPORT OF LONG RANGE NASA GOALS
- RESEARCH AREAS:
  - CONCURRENT PROCESSING
  - PARALLEL COMPUTING ARRAYS FOR SIGNAL PROCESSING
  - HIGH PERFORMANCE VLSI SIGNAL PROCESSORS
  - LARGE VOLUME DATABASE MANAGEMENT
  - TELECOMMUNICATIONS RESEARCH
  - HIGH SPEED LOCAL AREA NETWORKS
  - NETWORK GRAPHICS AND USER INTERFACE ARCHITECTURE
  - ADVANCED CONCEPTS FOR REMOTE SPACE SCIENCE OPERATIONS



Programmable Mask Technology

The objective of this program is to develop a vision system for space applications using the massively parallel capabilities of optical (coherent-light) information processing. Areas pursued include development of suitable programmable mask devices (and of impulse deconvolution methods for them), and also a hybrid distributed-processing system.

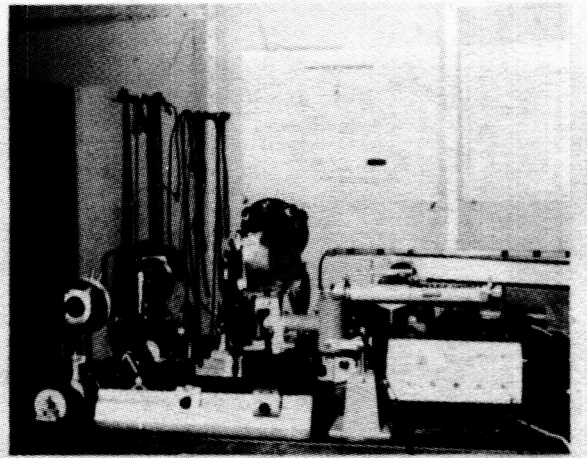
Programmable masks are as yet in a rudimentary state and methods of using them in vision systems also need development. The effects of the diffraction pattern of a single element, and methods of compensating for them, are one focus of the program. Another is the development of devices that have minimal effects for which to compensate. Yet another is the implementation of optical processing masks for various vision problems (e.g., discrimination and position estimation). And finally, a hybrid system that mimics nature by distributing the information processing to best advantage between the system's "retina" and the optical correlator will be constructed. This hybrid system will have a flexibly specified digital spatial mapping from a high resolution imager to the input modulator in the correlator.

Major contracted efforts in FY 85 were in development of the Texas Instruments spatial light modulator (SLM) and a correlator including that device as the optically active element (see opposite figure). One version of the new SLM configuration was tested. In-house efforts were made in the design of adaptive methods of using real devices and in the design of the programmable retina. All these efforts will come together in March 1986 with the delivery of the correlator system and its integration with the programmable retina at JSC.

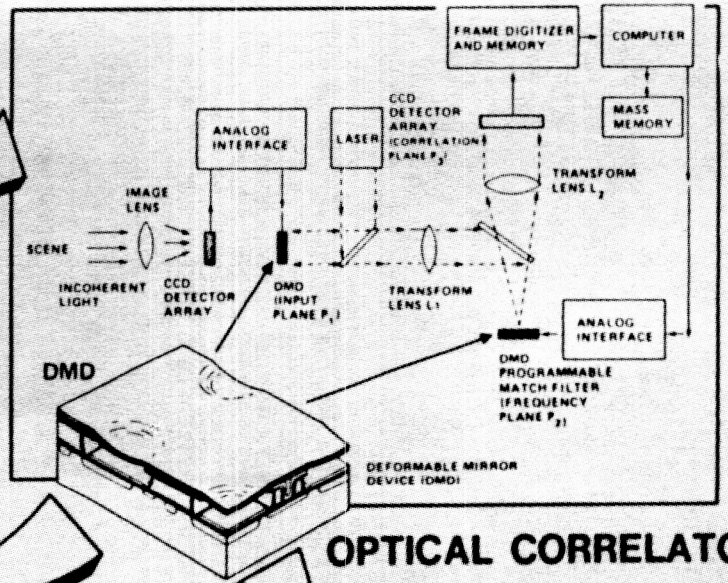
Joint research efforts with the U.S. Army are underway and are being sought with the Air Force and the National Bureau of Standards. In FY 85, a presentation of results and plans was made to both the NASA Technology Utilization Office and the armed services, with encouraging results.

TECHNICAL CONTACT: Richard Juday, JSC (713) 483-5391
Kumar Krishen, JSC (713) 483-2872

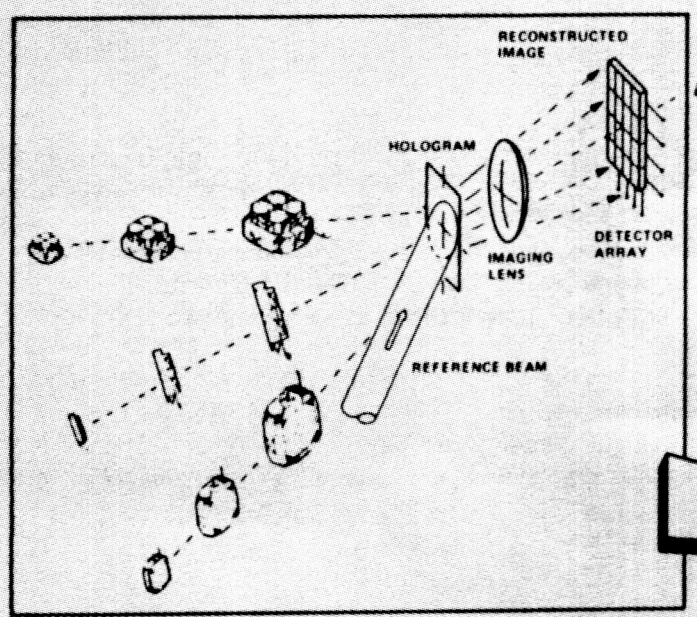
PROGRAMMABLE MASK TECHNOLOGY



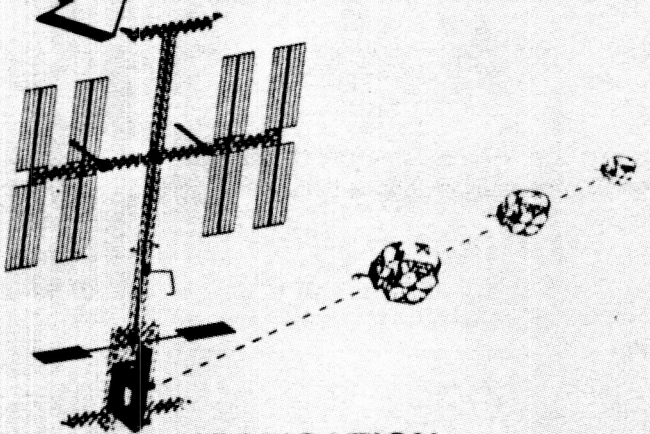
DEVICE TESTING



OPTICAL CORRELATOR



HOLOGRAPHIC VIEW STORAGE



APPLICATION

Optical Information Processing

Optical processing has inherent advantages over digital processing in that huge amounts of data can be manipulated in parallel and in real-time. The only disadvantage is that accuracy is sacrificed for real-time computing. Nonetheless, space and aeronautic applications abound. The system shown is a vital part of an expert system for pattern recognition. Other applications include matrix-matrix multiplications and systolic operations.

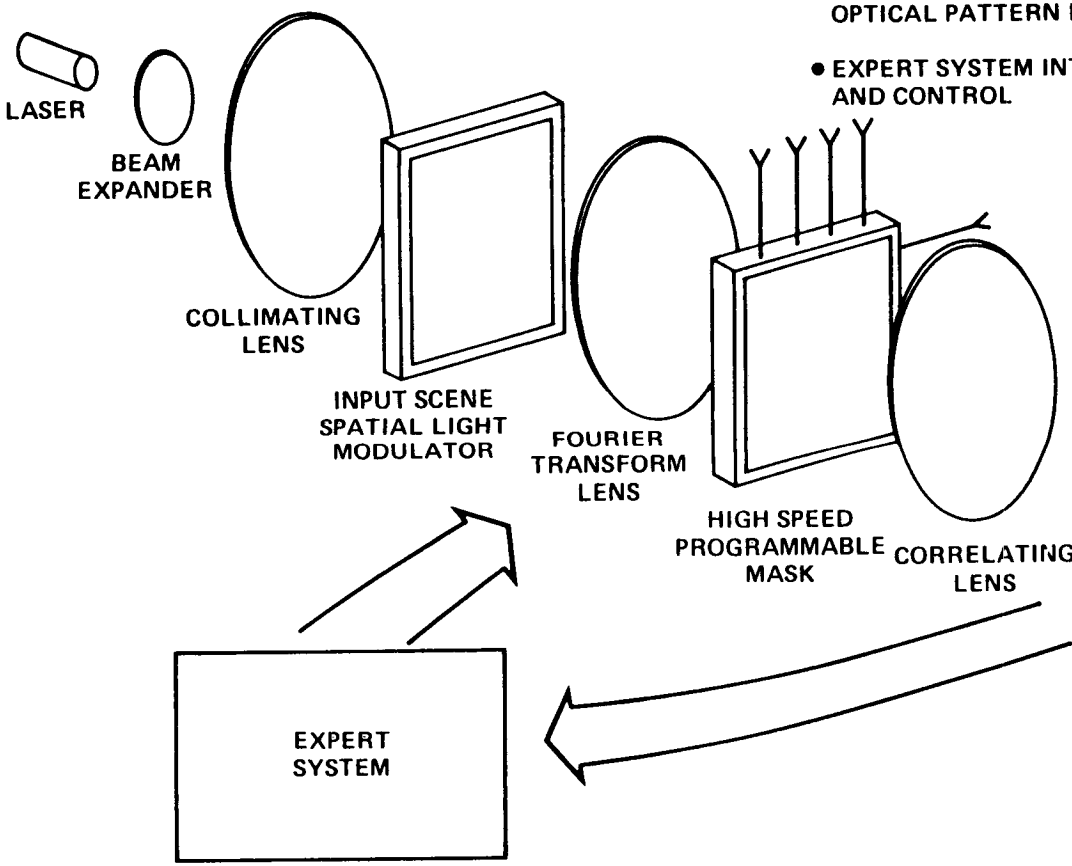
ARC has developed an LCD as a programmable mask and has successfully demonstrated its capability to perform mathematical operations. This LCD is used as the input scene spatial light modulator in a pattern recognition system. In the past, the LCD was used successfully as a device for a Hadamard Image Encoder.

TECHNICAL CONTACT: David Ennis, ARC (415) 694-6525

OPTICAL INFORMATION PROCESSING

PARALLEL INNOVATIONS:

- REAL-TIME MULTI-INVARIANT MULTI-CLASS OPTICAL PATTERN RECOGNITION
- EXPERT SYSTEM INTELLIGENT POST-PROCESSING AND CONTROL



APPLICATION:

SPACE STATION DATA PATTERN RECOGNITION AND MACHINE VISION

Hyperspectral Analysis

Hyperspectral analysis applied to remotely sensed spectral data provides the capability to identify surface materials based upon the unique spectral signatures of the material when analyzed in conjunction with a knowledge of the geological setting. The computer science objective of this work is to develop and demonstrate a new kind of expert system that can assist scientific investigators in the analysis of several kinds of space derived remote sensing data. The scientific objective is to develop and automate a technique that will identify surface materials by analysis of remotely sensed multichannel imaging spectrometer data.

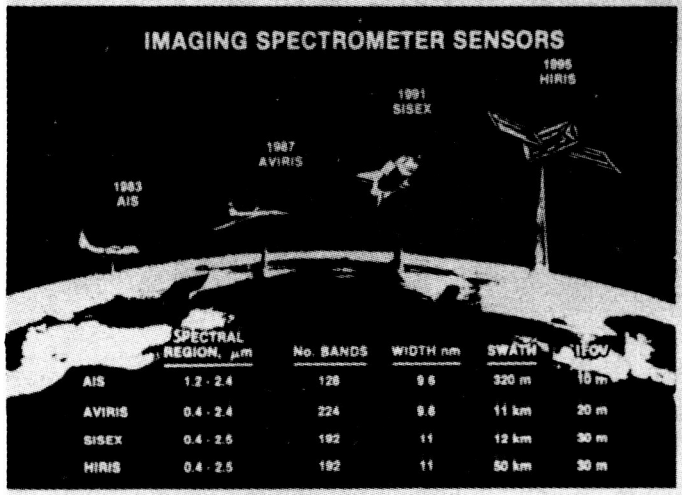
The instruments to be dealt with are: Airborne Imaging Spectrometer (AIS), 128 spectral bands, 32 pixel swath on the ground, currently operational; Airborne Visible and Infrared Imaging Spectrometer (AVIRIS), 224 spectral bands, 600 pixel swath, operational September 1986; Shuttle Imaging Spectrometer Experiment (SISEX), 192 spectral bands, 350 pixel swath, operation in 1991; and High Resolution Imaging Spectrometer (HIRIS), part of EOS payload, 192 spectral bands, 400 pixel swath.

Traditional analysis methods use statistical methods to analyze an image. These traditional statistical inference methods achieve materials discrimination, not identification, and require many hours of processing time on computers such as a VAX. The Hyperspectral Analysis approach provides direct material identification for each pixel, quantifies the fraction of each material identified in the pixels, and does that analysis with sufficient speed to make the process interactive with the operator working at a SUN workstation using a VAX for file manipulation. Analysis that would take about a month with traditional approaches is now being done in a couple of hours.

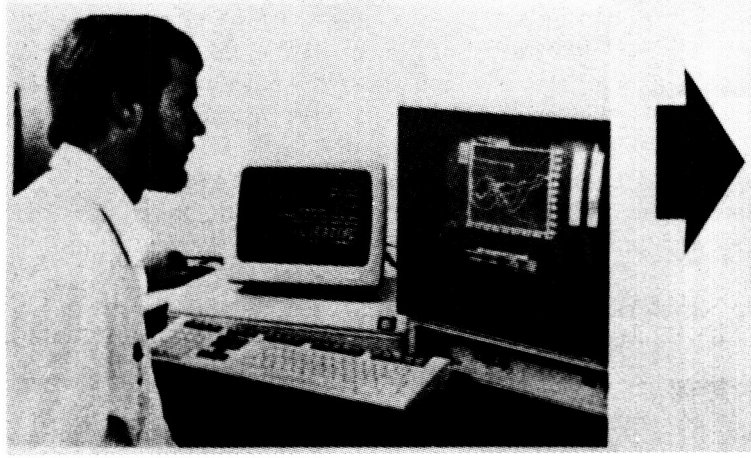
The approach combines symbolic computing (manipulation of objects and their relationships) with traditional numerical computation. The system uses a common programming language (the language C) in order to make the system portable between various kinds of computers. A SUN Microsystems workstation in a Unix environment is being used for the demonstration. The prototype system has achieved over 90% accuracy in mineral identification from airborne imaging spectrometer data from test sites in Nevada. The knowledge base for other geologic settings is in the process of being entered.

TECHNICAL CONTACT: Dr. Jerry Solomon, JPL (818) 354-2722

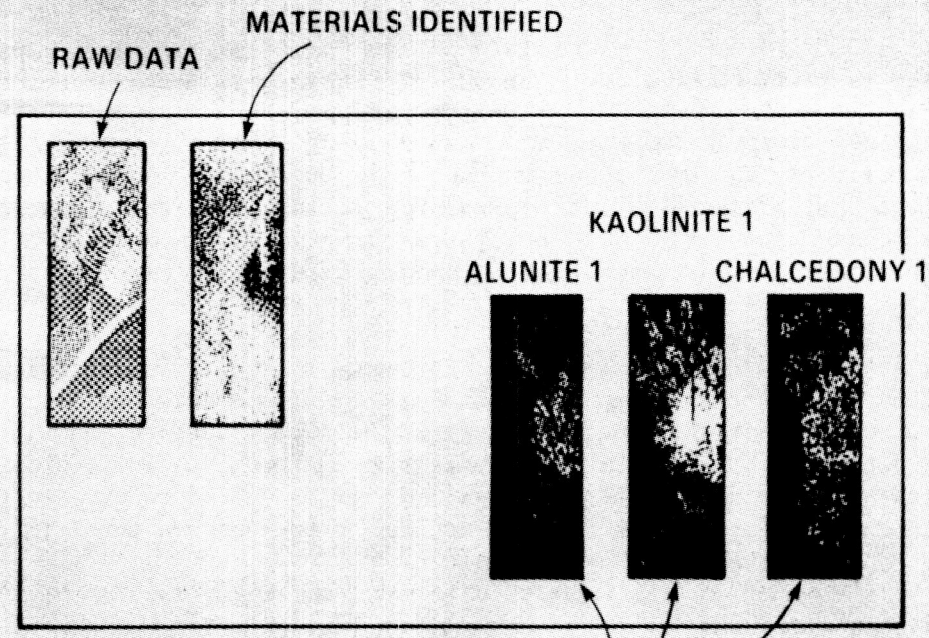
HYPERSPECTRAL ANALYSIS



	SPECTRAL REGION, μm	No. BANDS	WIDTH nm	SWATH	IFOV
AIS	1.2 - 2.4	128	9.6	320 m	10 m
AVIRIS	0.4 - 2.4	224	9.8	11 km	20 m
SISEX	0.4 - 2.5	192	11	12 km	30 m
HIRIS	0.4 - 2.5	192	11	50 km	30 m



AN EXPERT SYSTEM APPLIED TO IDENTIFICATION OF SURFACE MATERIALS FROM REMOTELY SENSED IMAGING SPECTROMETER DATA.



ARC Concurrent Processing Research

The Computer Science Research Program at ARC is concentrated in the areas of computer architectures for computational physics and computer graphics for computational and experimental physics. The computer architecture work is currently investigating three multiprocessor architectures - data flow, control flow, and systolic arrays.

The data flow work has been done in conjunction with MIT, and has defined at the instruction set level a static data flow architecture along with its programming language. The in-house effort has involved the development of a simulator for this architecture and the generation of input for this simulator which is typical of the computational fluid dynamics (CFD) calculations performed at ARC and elsewhere in the aerospace community. To date, the data flow concept has been successful in identifying a great deal of concurrent processing potential. However, key architectural bottlenecks have been discovered. These bottlenecks are due to limitations of available technology and are not felt to be a flaw in the concept of data flow architectures.

The control flow studies have been conducted in-house and in conjunction with Stanford. Performance measurement techniques have been developed which can be used at the various levels of problem definition, e.g., real world problem, model, numerical approximation, numerical method, algorithm, program, or executable machine code. Stanford is concentrating on the higher levels while the in-house work has concentrated on the actual execution of codes on multiprocessors such as the quad VAX 785 system and the CRAY X/MPs. Early success in efficiently mapping computational physics codes to control flow architectures prompted the development of extensions to FORTRAN and a precompiler which will permit researchers direct access to these multiprocessor architectures in a natural and efficient way. Testing of this precompiler will continue and user feedback incorporated into future versions.

In the area of systolic processors, a prototype systolic array for solving the diagonal systems which arise in Reynold-averaged Navier-Stokes solutions is currently under construction. This prototype will be configured by ZeroOne Systems, Inc., with off-the-shelf array processors, memories, and disks to determine if it is a viable competitor to the previously mentioned architectures.

Computer graphics involves both research and development. The opposite page shows a typical user application which makes use of the computer graphics codes developed under this program. These graphics packages permit the full utilization of the three-dimensional capabilities of the IRIS workstation. At present, no commercial package permits the dynamic manipulation of complex color shaded images such as that shown in the photo. The research has been concentrated in the area of finding better techniques for visualizing depth in three-dimensional images. Current research is in the area of stereo viewing, ray tracing, and sprinkling random dot patterns on transparent surfaces.

TECHNICAL CONTACT: Ken Stevens, ARC (415) 694-5949

CONCURRENT PROCESSING RESEARCH

PRODUCTS OF RESEARCH—

- ALGORITHMS FOR GENERATING SMOOTH CONTOURS FROM SPARSE RANDOM DATA
- THREE DIMENSIONAL GRAPHICS PRESENTATION OF EXPERIMENTAL AND COMPUTED DATA

Intelligent Data Management

The objective of this program is to develop intelligent value added services and systems that exhibit human intellectual capabilities and integrate them with existing database technologies to support the creation of advanced data management systems that can handle future data management needs. This will allow users to perform complex database operations with minimal knowledge of a database's architecture or language.

The approach used was to apply expert system and related AI technologies to develop intelligent data management processes. To date, the following progress has been achieved:

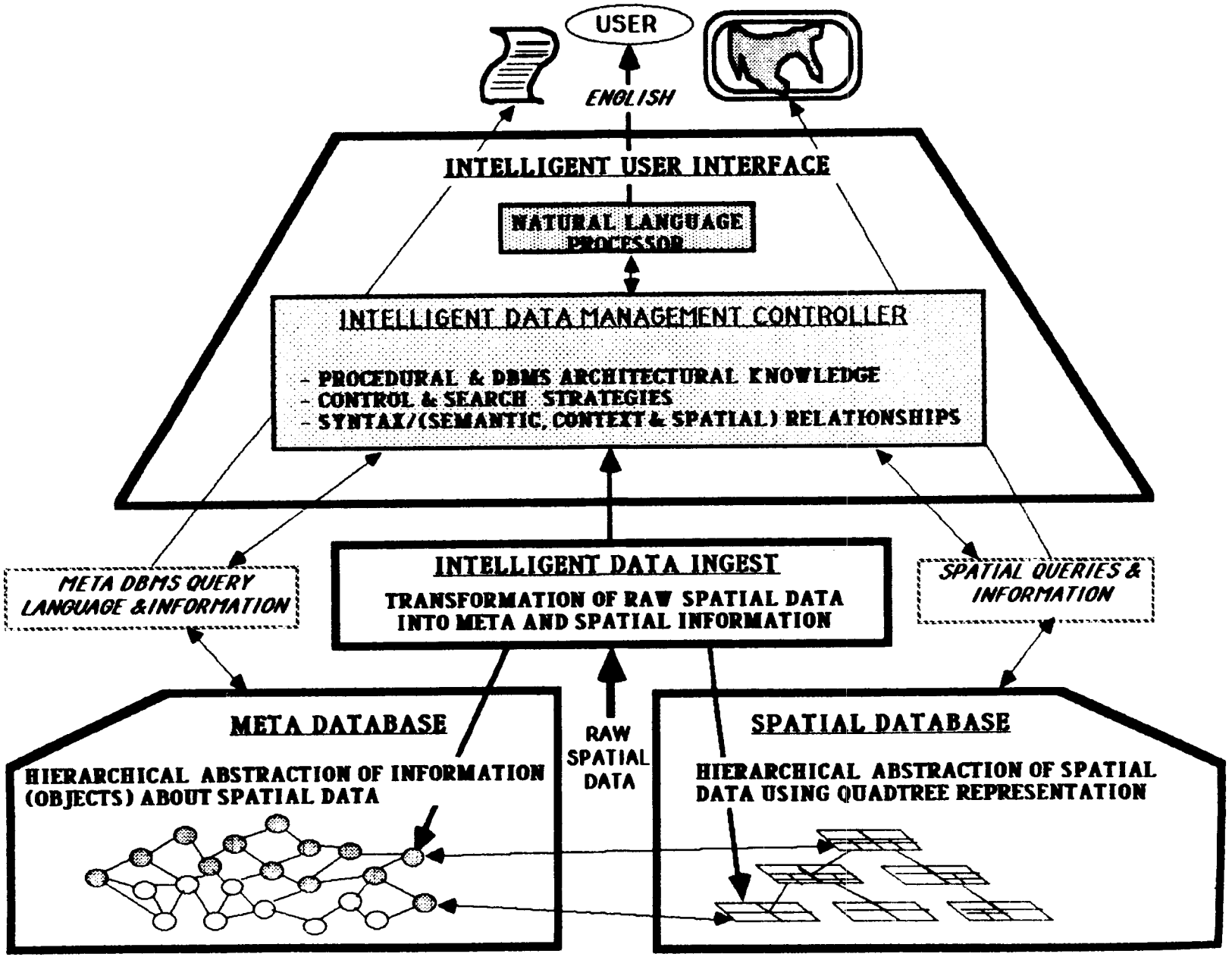
- Development of a detailed intelligent data management concept
- Design, development, and prototype fabrication of an intelligent data management controller, using expert system technology to access, validate, and demonstrate the project's design concepts and goals
- Interfacing with and demonstration of an expert system with a crustal dynamics database
- Implementation, interfacing, and demonstration of a natural language query processor to a crustal dynamics database which allows users to communicate with the database in plain English text.

Program follow-on goals for FY86 are based on further integration and test using expert systems and new concepts. Accomplishments projected for this phase include:

- Extension of capabilities of the intelligent data management controller using advanced expert system development tools that will support concurrent data driven and goal driven query requirements and learning by example from expert database users
- Interfacing of the natural language processor to an expert system based intelligent data management controller
- Evaluation and validation of the concept for an advanced dynamic DBMS architecture that can create real-time optimal data structures to support a specific query or set of queries.

TECHNICAL CONTACT: William J. Campbell, GSFC (301) 344-5876

INTELLIGENT DATA MANAGEMENT



Distributed Access View Integrated Database (DAVID) System

The objective of this project is to provide the fundamental research on the database uniformization problem so that NASA space data users can access any database independent of its physical distribution and specific organization. The approach used is to develop a solution to the database uniformization problem based on the recently developed framework called Database Logic. The proposed system, called DAVID (Distributed Access View Integrated Database), will be constructed on top of existing databases/database management systems. It will also provide facilities for the construction of new databases. Hence, DAVID can also be used as a stand-alone distributed homogeneous database management system.

A schematic breakdown of the DAVID system is given in the opposite figure. The functions of the packages shown in the DAVID DBMS block are described below. TERMINAL INTERFACE enables users to access databases through a computer terminal session. GSQL TRANSLATION breaks down a user's command in the language GSQL (Generalized SQL) into simpler Primitive GSQL commands. COMMUNICATIONS is responsible for sending the Primitive GSQL commands and data between different computers. DAVID GSQL PRIMITIVE evaluates the Primitive GSQL commands for databases stored in the DAVID database management system. HOST LANGUAGE INTERFACE PACKAGE enables users to access the distributed database in a wide choice of programming languages (e.g., C, FORTRAN, ADA, COBOL, etc.). GENERIC CLUSTER ACCESS is the single package that all of the different host language packages call.

FILE ACCESS provides the low level access to data stored in DAVID's own database management system. GSQL QUERY FORMULATOR helps the user to find out which databases contain what information and helps the user formulate a query. RESIDENT GSQL PRIMITIVE evaluates the Primitive GSQL commands on non-DAVID database management systems. CONSTRAINT REALIZATION supports semantic or integrity constraint maintenance over databases. VIEW UPDATE supports the updating of "virtual" or non-existing databases defined over actually existing distributed databases. CONCURRENCY CONTROL supports multiple user transaction processing (i.e., updating) over heterogeneous distributed databases. INSTALLATION & BACKUP provides for the normal loading of the DAVID system and handles recovery in the case of system or media failures. UTILITIES contains software tools that are used by many of the other packages.

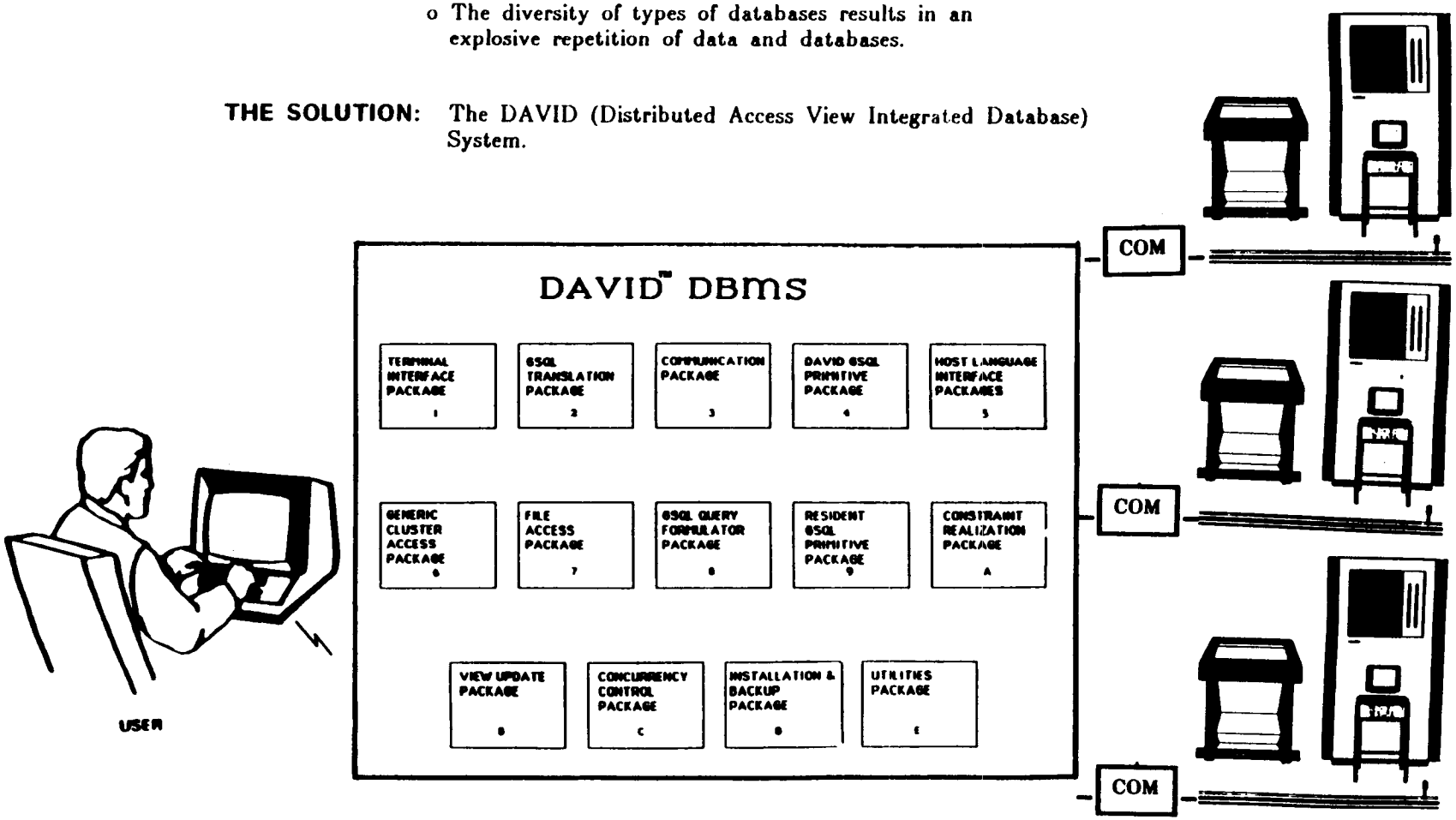
TECHNICAL CONTACT: B. E. Jacobs, GSFC (301) 344-5661

HETEROGENEOUS DISTRIBUTED DATABASE MANAGEMENT

THE PROBLEM: o NASA scientists and administrators have to learn many different access methods in order to obtain data.

o The diversity of types of databases results in an explosive repetition of data and databases.

THE SOLUTION: The DAVID (Distributed Access View Integrated Database) System.



Controls and Guidance - Aeronautics

The overall objective of the Aeronautics Controls and Guidance Program is to provide advanced technology for the improvement of future civil and military aircraft operations under all-weather conditions and for the development and exploitation of new concepts, design methodologies and flight systems to increase the efficiency, effectiveness, reliability and safety of new airplanes and rotorcraft. Major sub-elements include handling qualities and control theory, guidance and display concepts, flight crucial systems, and vehicle-specific controls and guidance for subsonic transports, rotorcraft, and fighter/attack aircraft.

The technology generated in the Aeronautics Controls and Guidance Program has potential application in the design, development, and operation of new civil and military aircraft. Vehicle-specific flight management technology for subsonic transports also has potential application in the operation of existing aircraft within the Federal Aviation Administration's air traffic control system. The Program involves analytical and experimental research performed by in-house, university and industry personnel and includes laboratory testing, ground-based simulation, and flight validation.

PROGRAM MANAGER: Richard J. Wasicko
NASA/OAST/RC
Washington, DC 20546
(202) 453-2704

Allowable Time Delays in Large Transport Responses

The present military flying quality specification allows a maximum time delay of aircraft response, regardless of airplane size or intended mission for Level 1 (satisfactory) handling qualities of not more than 0.1 seconds. However, many of today's large aircraft, having good flying qualities, have response lags much greater than 0.1 seconds. Therefore, it is believed that the present criteria for maximum allowable time delay are too stringent when applied to large aircraft whose large inertias result in maneuvering requirements and piloting tasks markedly different from those of fighter class aircraft. Furthermore, the potential imposition of larger-than-needed structural and actuation capabilities on large airplanes could make their design more expensive and operationally inefficient.

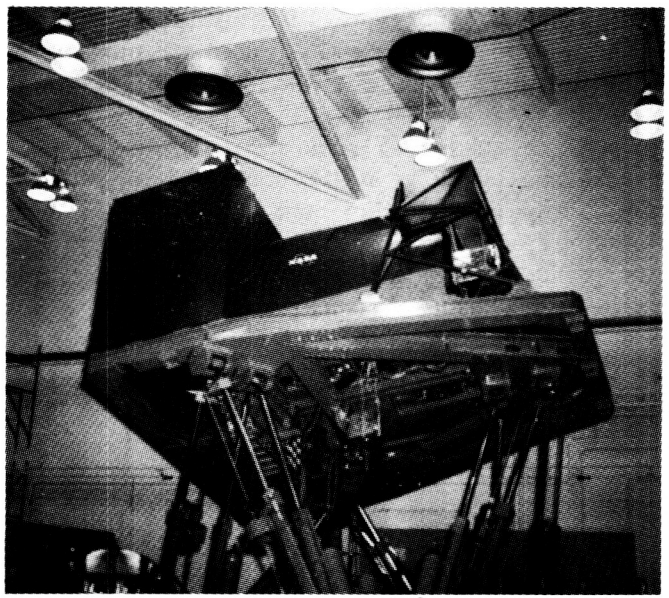
A piloted simulator investigation has been conducted utilizing the Visual Motion Simulator (VMS) and a mathematical model of a derivative Lockheed L-1011 transport. The objective of this study was to build on the existing large-aircraft data base in the area of control system delays and to utilize the results as the basis for suggested allowable response time delays for the various levels of handling qualities.

Preliminary analysis of the simulation results indicates that: (1) requirements for a 0.1 second maximum delay in aircraft response are much too conservative for large aircraft where an offset landing maneuver is the critical design task; (2) pilots are more tolerant of lagged time delays than they are of discrete time delays; and (3) delays in the lateral axis appear to be more critical than in the longitudinal axis. These simulator tests suggest Level 1 handling qualities limits for discrete time delays of 0.3 seconds in the lateral axis and 0.5 seconds in the longitudinal axis for large transports--as opposed to the universal 0.1 second limit of the present military specification.

TECHNICAL CONTACT: William Grantham, LaRC (804) 865-4681

ALLOWABLE TIME DELAYS IN LARGE TRANSPORT RESPONSES

Flying Quality Level	Allowable Delay, Sec		
	MIL-8785-C Specification, Sec (All axes/All aircraft)	Preliminary Results from Langley Simulator for Large A/C, sec	
		Pitch	Roll
1 (SATISFACTORY)	0.10	0.5	0.3
2 (ACCEPTABLE)	0.20	1.0	0.7
3 (UNACCEPTABLE)	0.25	1.3	0.9



VMS

L-1011

Optimal Control in Wind Shear

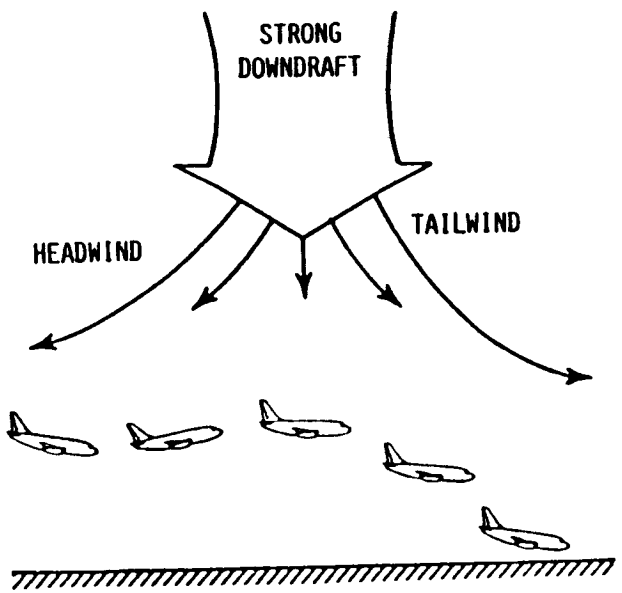
Low altitude wind shear is recognized as an infrequent but significant hazard to all aircraft during the takeoff and landing phases of flight. It is characterized by rapid changes in wind magnitude and direction, and has been a contributing cause of several major transport accidents in recent years.

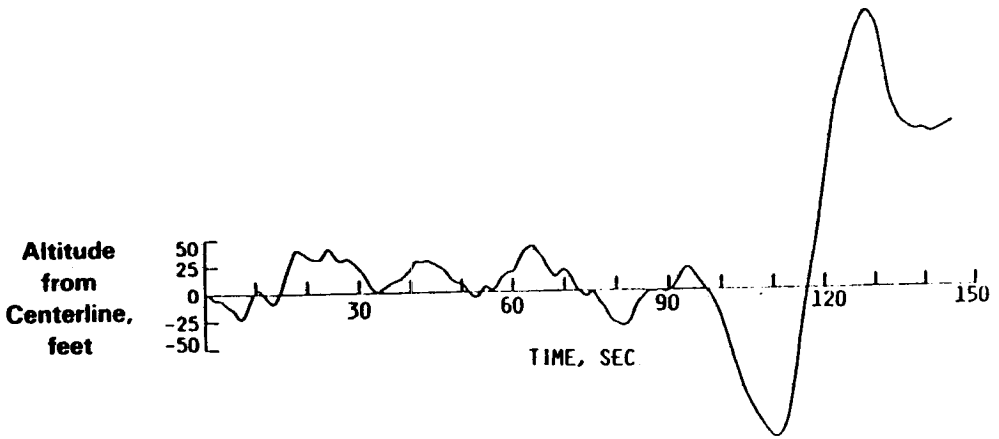
Research has been conducted to evaluate an optimal output feedback design of an automatic longitudinal control system for a transport aircraft to assess its ability to successfully penetrate a severe wind shear relative to the capabilities of a conventionally-designed control system. The Advanced Transport Operating Systems' Transport Systems Research Vehicle (TSRV) was used in the nonlinear simulation, which included a wind shear and gust model reconstructing the hazardous environment experienced during a 1975 landing accident. The evaluation also included a comparison of the optimal output feedback design and the existing TSRV autoland control system, a conventional design that had previously been shown to be somewhat resistant to wind disturbances including wind shear.

Results of the study indicated that the output feedback control system design was much more effective in a severe wind shear and gust environment than the TSRV autoland system. Glideslope tracking was much tighter for the output feedback design, which also provided better attitude and airspeed control with less elevator and throttle activity than the conventional autoland system. It is planned to verify these results by flight testing the output feedback control system on the TSRV B-737 aircraft in 1986.

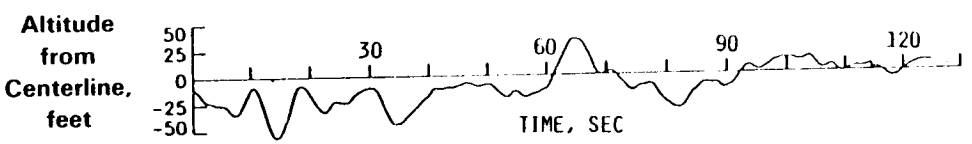
TECHNICAL CONTACT: Christine M. Belcastro, LaRC (804) 865-3934

OPTIMAL CONTROL IN WIND SHEAR





CONVENTIONAL CONTROL SYSTEM DESIGN



OPTIMAL FEEDBACK CONTROL SYSTEM DESIGN

Full-Color Electroluminescent Flat-Panel Display

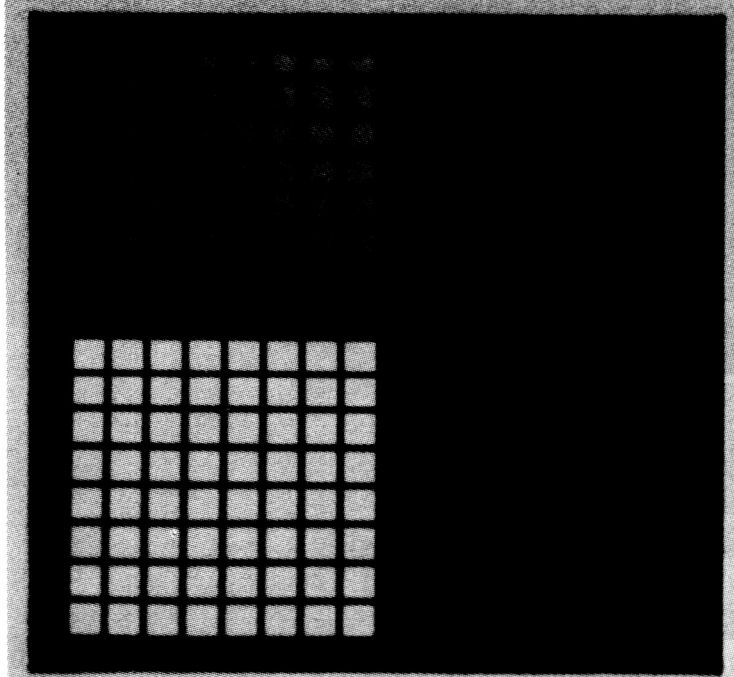
Today's advanced transport aircraft are using electronic displays to replace electromechanical instruments in the cockpit. The color CRT is currently filling this display role, but flat-panel displays are urgently needed because of the space limitations in the cockpit. Matrix-addressed TFEL (thin-film electroluminescent) displays are prime candidates for the flat-panel displays to replace the bulky CRT. These TFEL displays are, however, only available in monochrome form. Full-color or multicolor displays are needed to display the new electronic instrument formats.

The goal of producing full-color TFEL displays is being pursued by a joint Army/Navy/NASA contractual research effort. The first phase of this effort was to develop usable red, green, and blue primary-color phosphors. The second phase calls for the design and fabrication of a full-color TFEL display using these phosphors. Phase II is already underway (a research contract to Planar Systems, Inc.) and is utilizing the research approach of fabrication and testing of progressively more complex multicolor TFEL devices.

A two-primary color, flat-panel, Thin-Film Electroluminescent (TFEL) display has been successfully fabricated. The display is a laboratory breadboard, 1 inch x 1 inch, with a resolution of 16 lines/inch (see opposite figure). Developed primarily to test phosphor systems and multilayer construction/addressing techniques, the device is made by superimposing a green EL display and a red EL display, giving the choice of red, green, or yellow (red + green) at each picture element. The display produces vivid colors, and accomplishes an exciting step on the way to developing full-color flat-panel TFEL displays to replace the bulky color CRT.

TECHNICAL CONTACT: James B. Robertson, LaRC (804) 865-3716

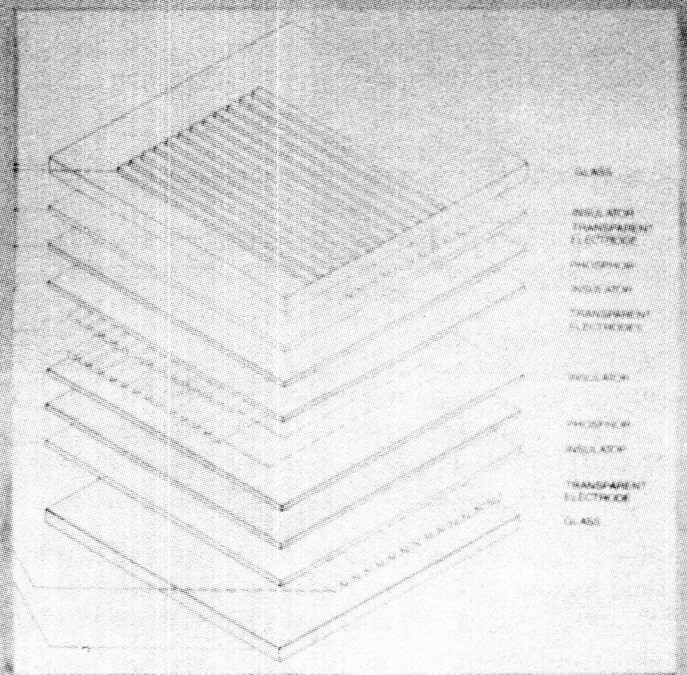
FULL-COLOR ELECTROLUMINESCENT FLAT-PANEL DISPLAY



LABORATORY DISPLAY

1 IN. X 1 IN.

16 LINES/IN.



DISPLAY CONSTRUCTION

STACKED SUBSTRATES

GREEN OVER RED PHOSPHORS

Verification Technology for Digital Flight Control Systems

Research to develop, assess, and enhance tools and techniques for the verification of digital flight control systems (DFCS) has included the development of the DFCS Verification Laboratory (DFCSVL). This facility provides a user-oriented environment for the conduct of research activities on promising state-of-the-art verification tools and techniques. This laboratory includes a representative near-term DFCS, an integrated package of sofware verification tools, and hardware/system verification capabilities.

In Fiscal Year 1985, the verification technology activities included the following:

- Assessment of the technical and cost effectiveness of advanced software verification tools. Initial assessments have shown that the effectiveness of specific tools is related to how well the tool's syntax analyzer matches the target language compiler. A final report by the Boeing Commercial Airplane Company will be prepared in FY 1986.

- A Stanford University study which has confirmed that assertion testing is highly effective in detecting errors in flight control software. Also, new ways to optimize assertion testing were explored and resulted in two major developments: a) methodology for writing assertions based on calculation of a "Data Dependency" factor for system variables; and b) a method for reducing the overhead of assertions by using a "Watchdog Task" system for concurrent execution of assertions.

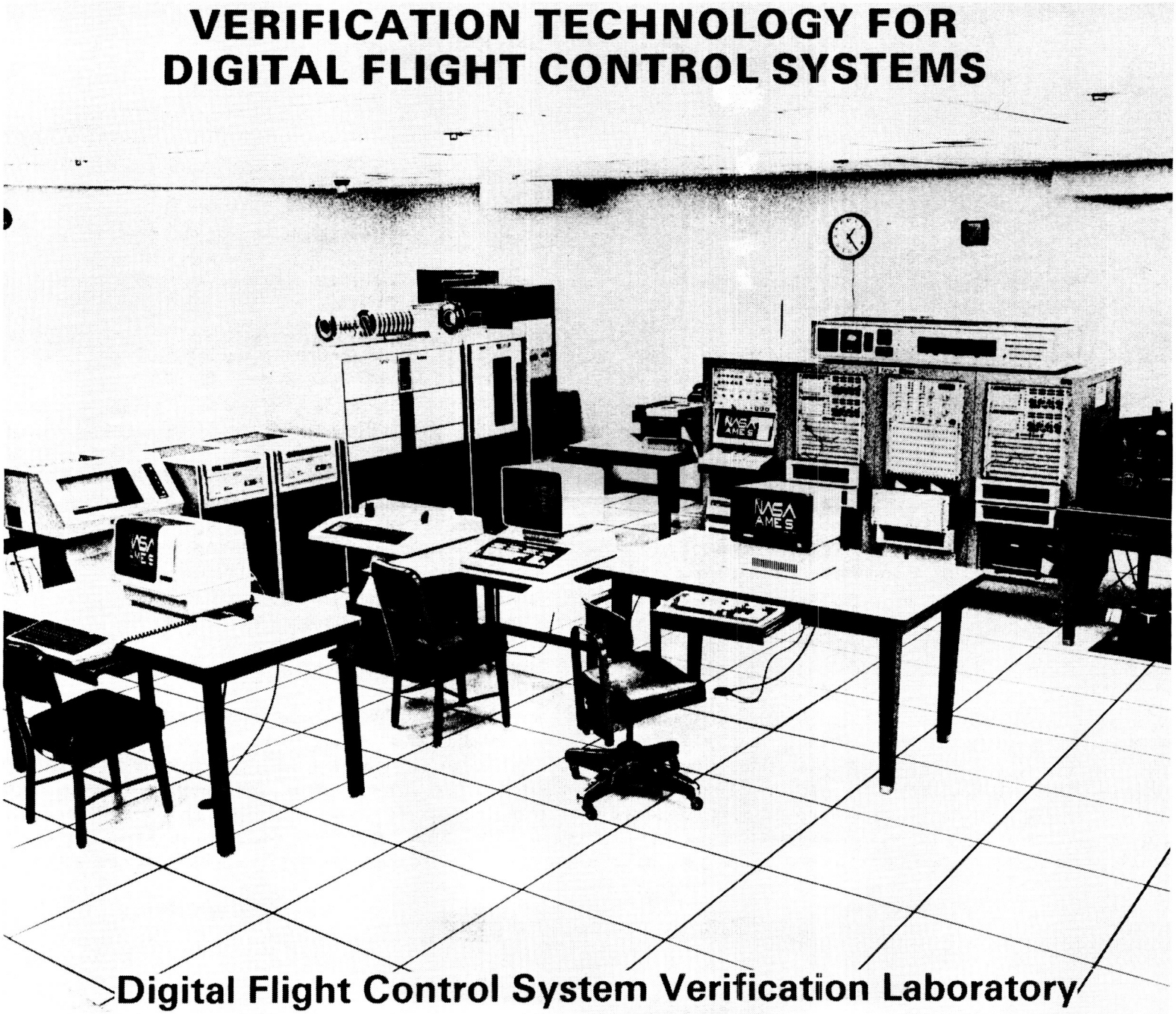
- Design of a specification language to describe generic flight software functions. This is an important element of the automated stress testing technique, which dynamically tests DFCS modules over a large input data range.

- Seeding of flight software with errors in type and frequency to correspond to the existing software error database.

- Systems level verification research focused on FAA sponsored activities with Lockheed-Georgia Company into verification of advanced DFCS redundancy levels. Reliability estimation, failure effects analysis, and system simulator methods were combined into an integrated approach.

TECHNICAL CONTACT: D. Doane/J. Saito, ARC (415) 694-5048

VERIFICATION TECHNOLOGY FOR DIGITAL FLIGHT CONTROL SYSTEMS



Digital Flight Control System Verification Laboratory

The SURE Reliability Analysis Program

Recently, a new mathematical theorem was proven which enables the efficient computation of the death state probabilities of a large family of semi-Markov models which are useful for the reliability analysis of fault-tolerant architectures. A major advantage of this new approach is that an arbitrary recovery transition can be handled. This is important since recent fault injection experiments on the Fault Tolerant Multi-Processor (FTMP) computer system have demonstrated that fault recovery does not fit an exponential distribution, as assumed by existing automated tools. The new mathematical method provides a means for bounding the probability of entering a death state of a semi-Markov model using simple parameters of the model such as the means and variances of the transitions.

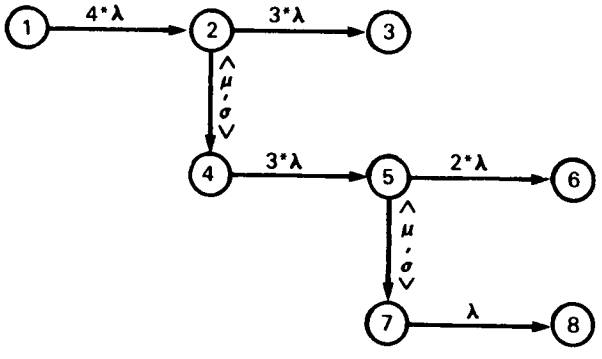
The Semi-Markov Unreliability Range Evaluator (SURE) computer program fully automates the new mathematical theory. The program processes a simple model description language and automatically computes and plots the probability of system failure as a function of model parameters. Although an exact answer is not produced by the SURE program, the calculated bounds are close together for reliability models of ultra-reliable systems—usually within 5% of each other. The advantage of the SURE technique is that the bounds are algebraic in form and consequently are computationally efficient. Very large and complex models can be analyzed by the program. Furthermore, the technique applies to the general class of semi-Markov models and thus does not impose restrictions on the type of architecture that can be analyzed. Because of the computation speed of the program, SURE can perform rapid sensitivity studies and thus serves well as a design tool.

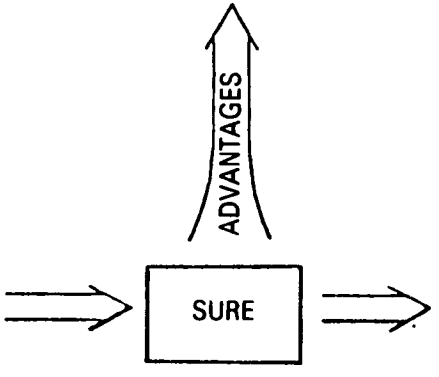
Industry has become involved in testing and evaluating the SURE computer program. It is planned to release the program to COSMIC after it has been validated.

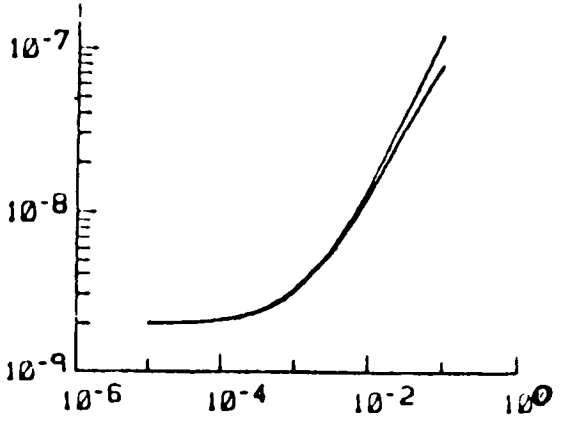
TECHNICAL CONTACT: Ricky W. Butler, LaRC (804) 865-3681

THE SURE RELIABILITY ANALYSIS PROGRAM

- VERY FAST
- DIRECTLY UTILIZES EXPERIMENTAL DATA
- CAN ANALYZE ANY FAULT-TOLERANT ARCHITECTURE







USER INPUT: MODEL OF COMPUTER/SYSTEM ARCHITECTURE

E.G., FAULT TOLERANT PROCESSOR
- FIMP
- SIFT
- AIPS

INDUSTRY INVOLVEMENT:
GENERAL ELECTRIC
SPERRY FLIGHT SYS.
BOEING COMMERCIAL
BOEING MILITARY
LOCKHEED GEORGIA, DRAPER LABS

PROGRAM OUTPUT:
PROBABILITY OF FAILURE AS A FUNCTION OF MEAN RECONFIGURATION TIME

Digital System Lightning Upset Assessment

The objective of lightning upset assessment research is to develop and validate a methodology to assess the upset susceptibility/reliability of flight-critical digital systems that are subjected to analog electrical transients induced by lightning. This research is motivated by the projected use in advanced aircraft of flight-critical digital electronic controls which are potentially more susceptible to upset by electrical transients than previous analog electronic systems.

A methodology has been developed to assess a digital system for lightning upset susceptibility and its impact on system reliability. The approach is to characterize induced transients using electromagnetic modeling based on lightning strikes to an F-106 aircraft and assess upset susceptibility to these transients. Complementary analytical and laboratory techniques for determining the response of digital systems to transient disturbances are being developed. Analysis of the collected upset data enables identification of critically susceptible system operations, development of hardening techniques and design modifications, and evaluation of upset susceptibility/reliability. The analytical approach separates the system into appropriate interface and functional elements. The interface circuitry is then analyzed in the classical manner using the SCEPTRE (System for Circuit Evaluation of Transient Radiation Effects) computer-aided circuit analysis code to determine the digital equivalent of the upsetting electrical analog transient. The manifestation of the upset in the digital system is then analyzed using a digital emulation code. In the laboratory approach, the response of the Unit Under Test (UUT) to randomly injected transients is compared with an unperturbed Reference Unit operating in bit synchronism with the UUT. Since the severity of system errors can only be defined in the context of performing an intended function, upset susceptibility/reliability of control systems cannot be inferred from that of general-purpose systems. Therefore, upset research efforts involve the application of the upset assessment methodology to a digital controller used onboard aircraft.

A limited-authority engine controller provided and supported under a contract with the Hamilton Standard Division of United Technologies is the first candidate controller for application of the upset assessment methodology. The Hamilton Standard controller is based on a microprocessor with a complete and accurate technical description and will, therefore, facilitate further development of simulation and analysis techniques. Engine control application software will be provided with an input data set that reflects engine performance corresponding to ten different operating conditions during flight. Future plans include the upset susceptibility assessment of a full-authority, fault tolerant engine controller that will interact with a dynamic engine simulation in closed-loop fashion.

TECHNICAL CONTACT: Celeste M. Belcastro, LaRC, (804) 865-3681

DIGITAL SYSTEM LIGHTNING UPSET ASSESSMENT

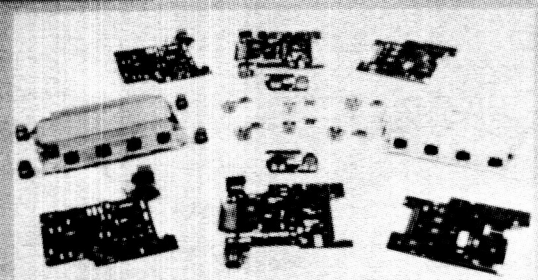
Methodology Development

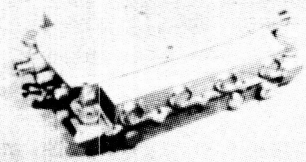
Transient Fault Injection

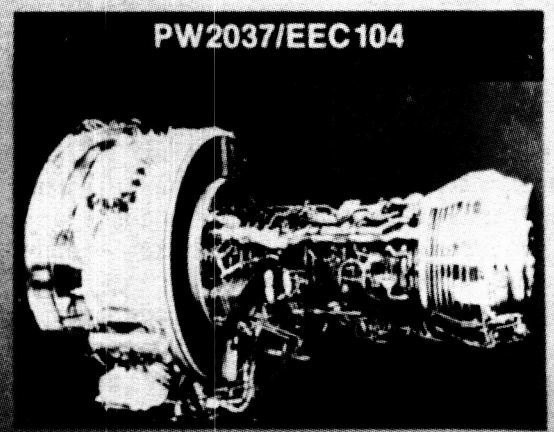
Analytical Methods

SCEPTRE Circuit Analysis → Emulator

Application







- Hamilton Standard Engine Controller

Total Energy Control System

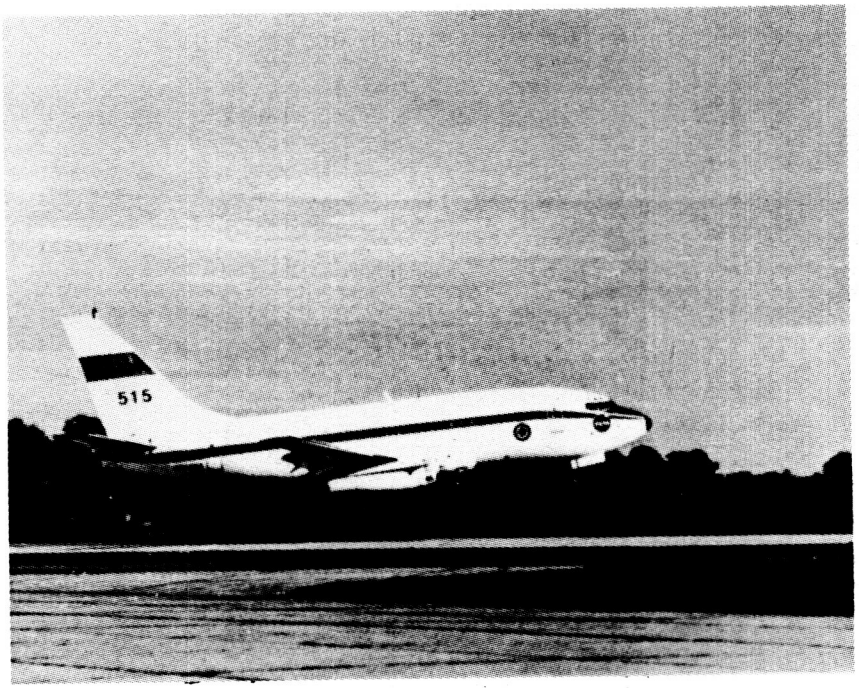
Virtually every automatic flight control system in use today by transport aircraft has been designed using a single-input, single-output control strategy. Although the elevator control loop can be closed on either speed or flight path, autopilot path control modes have become the most widely used. Automatic speed control, using the throttles, was then developed as a natural complement to the autopilot path control modes. This historic system evolution has not resulted in optimum automatic flight control system capabilities and performance. For certain flight conditions, the autopilot path control at constant thrust can produce speed instabilities, while autothrottle speed control at constant elevator angle can result in path instability. Together, the conventional autopilot and autothrottle can provide stable flight path and speed control. However, the operation is far from coordinated and can result in undesirable responses.

The Total Energy Control System (TECS) concept is unique in that it incorporates a full-time autothrottle which controls the total energy of the aircraft and utilizes the elevator to distribute the energy between speed and flight path angle. Designed by the Boeing Commercial Airplane Company, TECS has a generalized structure which is largely airplane independent. This offers significant cost reductions associated with development, testing, and verification of the flight software for new airplane applications. The major operational benefit of the system is the elimination or reduction of throttle activity due to flight path perturbations.

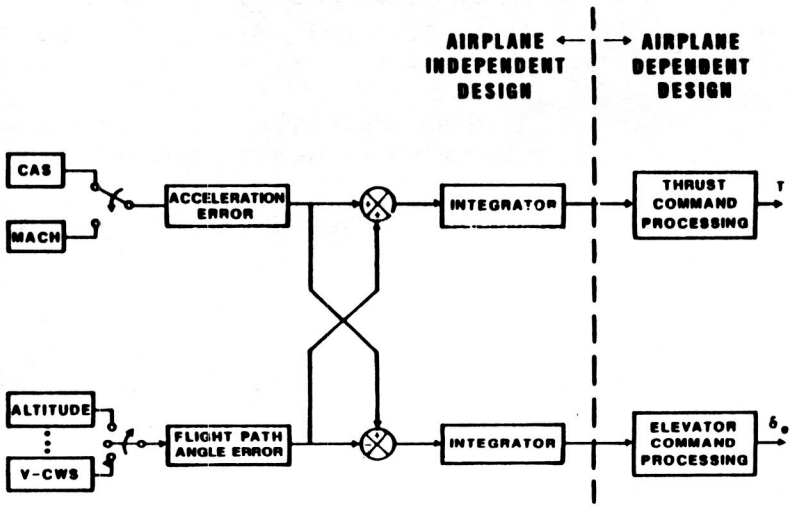
Ground-based simulator and flight tests of the Total Energy Control System concept were successfully completed during FY 1985 as part of the Advanced Transport Operating Systems program. The Transport Sytems Research Vehicle (TSRV) B-737 aircraft was used to demonstrate the benefits of this multi-input, multi-output integrated control system design. The benefit of reduced throttle activity was readily apparent during the flight tests.

TECHNICAL CONTACT: James R. Kelly, LaRC (804) 865-3621

TOTAL ENERGY CONTROL SYSTEM

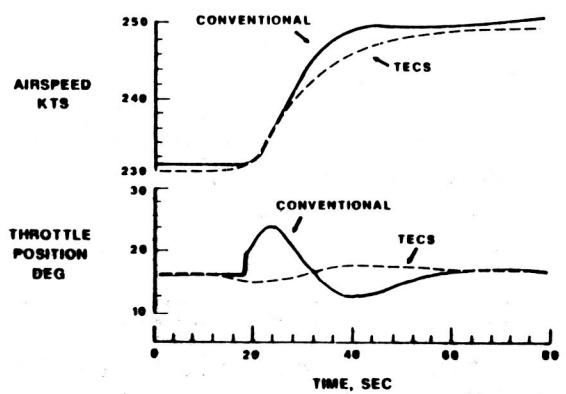


SIMPLIFIED IMPLEMENTATION OF TOTAL ENERGY CONTROL CONCEPT



ALTITUDE–AIRSPEED ENERGY EXCHANGE

(CONVENTIONAL SYSTEM vs TECS)



Applications of State Estimation in Aircraft Flight-Data Analysis

Accurate determination of aircraft motions from noisy or incomplete measurements is important in the analysis of flight data. For flight tests of new aircraft, the measurements often contain significant errors which must be identified before the data are used in performance calculations. Furthermore, direct measurements of certain important dynamic variables may be unreliable or impractical to perform. A similar problem occurs in the analysis of aircraft accidents and incidents, where the actual motions may have to be determined from a very limited data set. These problems are being solved by the analytical method known as state estimation.

An advanced state estimation program called SMACK (SMoothing for Air Craft Kinematics) has been developed. (Details about this program and its varied applications were published in the AIAA Journal of Aircraft, July 1985.) This state estimation technique is being applied to determine the severity of winds and turbulence encountered in flight using data from the digital flight data recorders onboard wide-body airliners, along with ATC surveillance radar data. A list of recent and ongoing applications follows:

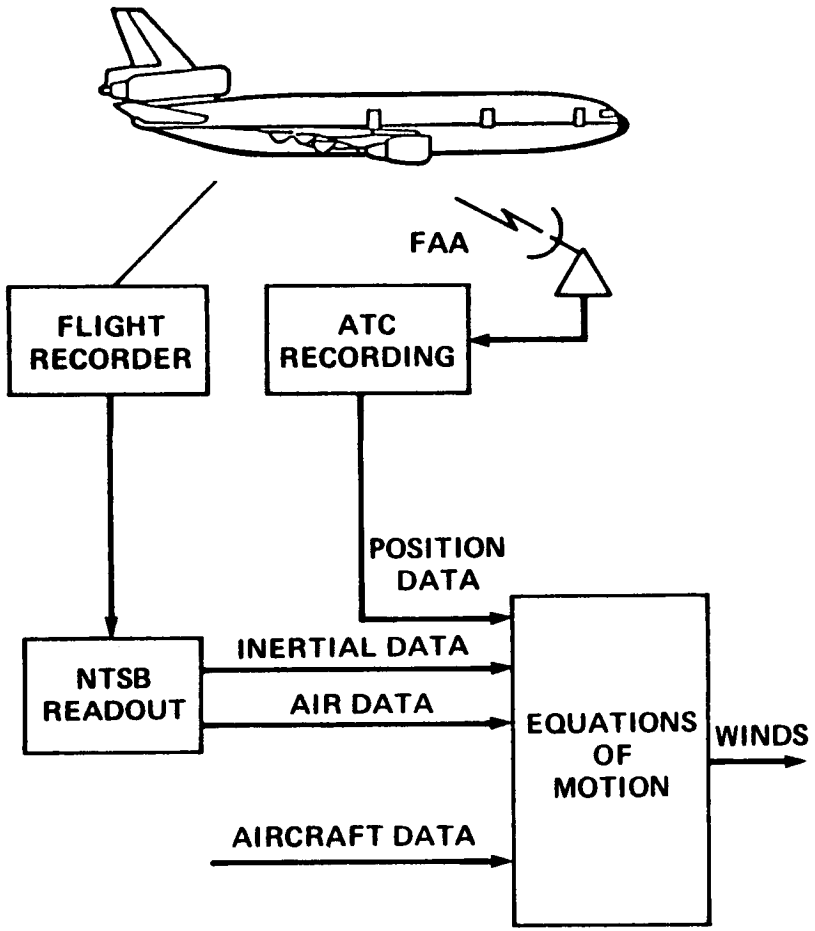
	Aircraft	Location	Date
1.	DC-10	Hannibal, Missouri	April 1981
2.	DC-10	Morton, Wyoming	July 1982
3.	DC-10	Atlantic Near Bermuda	October 1983
4.	L-1011	Offshore South Carolina	November 1983
5.	DC-10	Calgary, Canada	November 1975
6.	B-747	Over Greenland	January 1985
7.	B-747	Over Greenland	February 1985
8.	B-747SP	Offshore California	February 1985
9.	L-1011	Dallas/Ft. Worth, Texas	August 1985

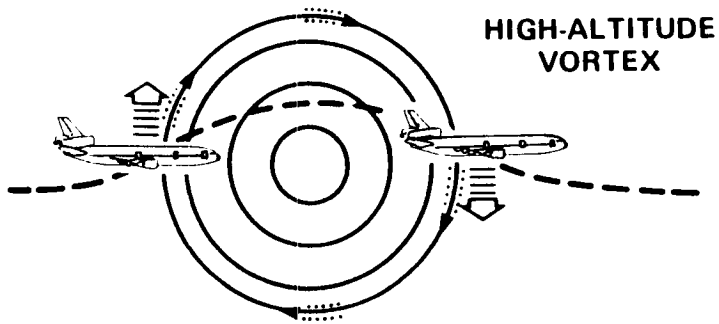
The first seven involved severe turbulence encounters at cruise altitude. Case 8 involved atmospheric disturbances and engine failure at cruise altitude. Case 9 involved a microburst encounter during landing approach.

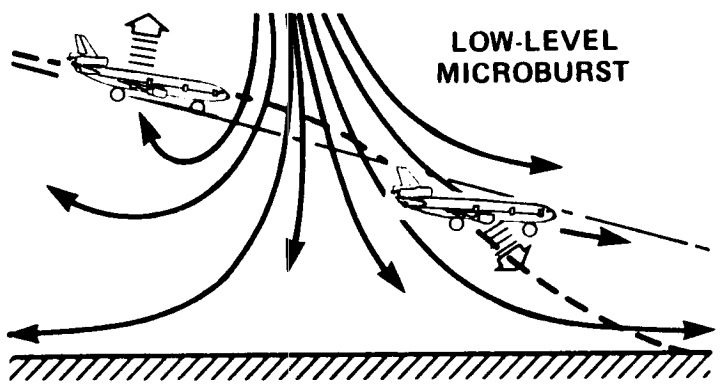
Analysis of data from flights involving severe turbulence at cruise altitude indicates that the aircraft encountered vortex arrays caused by a breakdown of wind shear layers (Kelvin-Helmholtz instability). The analysis also indicates that the vortices can be up to 1,200 feet in diameter, at spacings of about 3,000 feet, with whorls of wind above 80 feet per second. These vortex parameters obtained from airline flight data provide a way to simulate and investigate the oprational problems for other types of aircraft that may unexpectedly encounter this severe turbulence.

TECHNICAL CONTACT: R. Wingrove/R. Bach, ARC (415) 694-5429

APPLICATIONS OF STATE ESTIMATION IN AIRCRAFT FLIGHT-DATA ANALYSIS







Beacon Landing System (BLS) and Portable Tactical Approach Guidance (PTAG)

A Beacon Landing System (BLS) based on a novel, precision approach concept has been developed and flight tested as a part of NASA's Rotorcraft All-Weather Operations Research Program. In conjunction with this program, NASA also has been working with the USAF's Airbase Survivability Group at Eglin Air Force Base to apply BLS technology in the development and flight test of a Portable Tactical Approach Guidance system (PTAG). These systems are based on state-of-the-art X-band radar technology and digital processing techniques.

The BLS and PTAG airborne hardware consists of an X-band receiver and a small microprocessor, installed in conjunction with the aircraft instrument landing system (ILS) receiver. The microprocessor analyzes the X-band, BLS or PTAG input pulses and outputs ILS-compatible localizer and glideslope signals. The BLS ground station combines both localizer and glideslope into a single inexpensive, portable unit; it weighs less than 70 lbs and can be quickly deployed at a landing site. PTAG has separate ground stations for localizer and glideslope which allows for a more conventional ILS-type split-site installation. The PTAG ground stations each weigh less than 85 lbs.

Results from the flight-test program which was completed in Fiscal Year 1985 show that the BLS has a significant potential for providing rotorcraft with low-cost, precision instrument approach capability in remote areas. PTAG has also shown great promise for use in a battle damaged airfield mission scenario for both fixed-wing and rotorcraft operations.

TECHNICAL CONTACT: T. Davis, ARC (415) 694-5452

BEACON LANDING SYSTEM (BLS) AND PORTABLE TACTICAL APPROACH GUIDANCE (PTAG)

OBJECTIVE

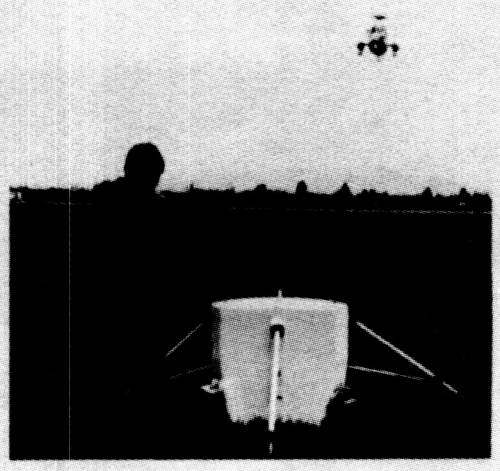
DEMONSTRATE THE FEASIBILITY OF LOW COST, X-BAND PRECISION APPROACH CONCEPTS FOR USE IN BATTLE-DAMAGED AIRFIELD MISSION SCENARIOS AND FOR REMOTE-SITE ROTORCRAFT OPERATIONS

APPROACH

- COMBINED LOCALIZER/GLIDESLOPE (BLS)
  - SMALL-67 lb TOTAL; BATTERY POWERED
  - RADAR BEACON BUILT IN
- SPLIT LOCALIZER/GLIDESLOPE (PTAG)
  - MAN-PORTABLE; BATTERY POWERED
  - EACH GROUND STATION LESS THAN 85 lbs TOTAL
- MINIMUM AIRCRAFT MODIFICATIONS
  - ILS COMPATIBLE OUTPUTS
  - NO ADDITIONAL COCKPIT SWITCHES

ADVANTAGES

- FILLS A VOID FOR PORTABLE OR REMOTE-SITE LANDING SYSTEMS
  - NEAR-TERM AVAILABILITY
  - SIMPLE AND INEXPENSIVE
- NO ADDITIONAL PILOT TRAINING REQUIRED



Rotorcraft Systems Integration Simulator Upgrade to Vertical Motion Simulator

The United States Army and NASA are jointly developing the Rotorcraft Systems Integration Simulator (RSIS) - an upgrade to the Vertical Motion Simulator (VMS). The objective of the RSIS upgrade is to provide a simulation facility for rotorcraft vehicle development and R&D programs particularly focusing on the demanding task of nap-of-the-earth (NOE) flight operations.

The simulator upgrade comprises a new computer-generated-imagery (CGI) system and significant improvements to the motion system. The CGI includes an Evans and Sutherland CT-5A image generator coupled to a wide field-of-view (FOV) dome projection system. The motion system upgrade replaces the existing training motion base, which sits on the VMS carriage with a high-performance motion system that provides uncoupled rotational degrees of freedom and 10 feet of longitudinal travel.

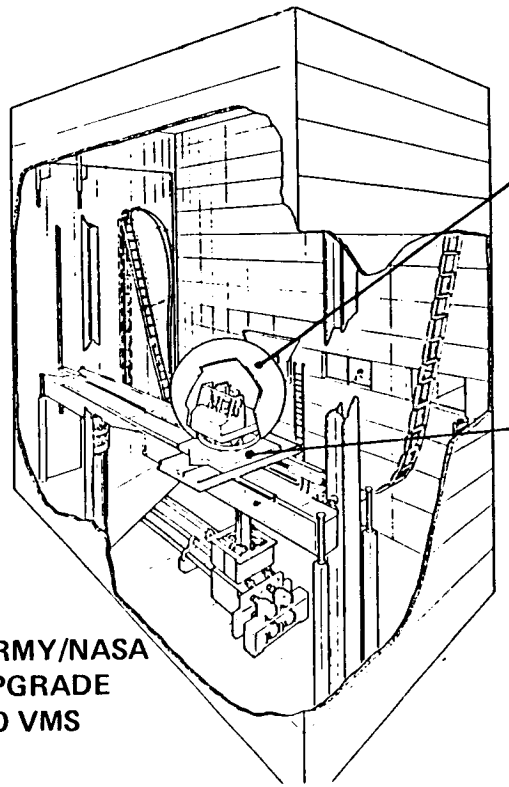
The new motion generator was delivered to NASA in Fiscal Year 1985 and is undergoing design improvements prior to integration with the CGI for systems checkout and ultimate integration on the VMS. The CGI underwent final assembly and checkout at the manufacturers plant and will be delivered to NASA in early 1986. It is anticipated that the VMS integration will start in mid 1986.

TECHNICAL CONTACT: Col. A. Deel, ARC (415) 694-5168

ROTORCRAFT SYSTEMS INTEGRATION SIMULATOR UPGRADE TO VERTICAL MOTION SIMULATOR

OBJECTIVE

- IMPROVED ROTORCRAFT VEHICLE DEVELOPMENT/EVALUATION
- ADVANCED R&T



- STATE-OF-ART CGI
  - WIDE FOV
  - COMBAT DATA BASE
- ENHANCED MOTION FOR NOE MANEUVERING

ARMY/NASA UPGRADE TO VMS

THRU

- UNSURPASSED ROTORCRAFT R&D SIMULATION FACILITY

PAYOFF

- INCREASED MISSION EFFECTIVENESS
- DECREASED DEVELOPMENT COST/RISK

Rotorcraft Air Combat Simulation

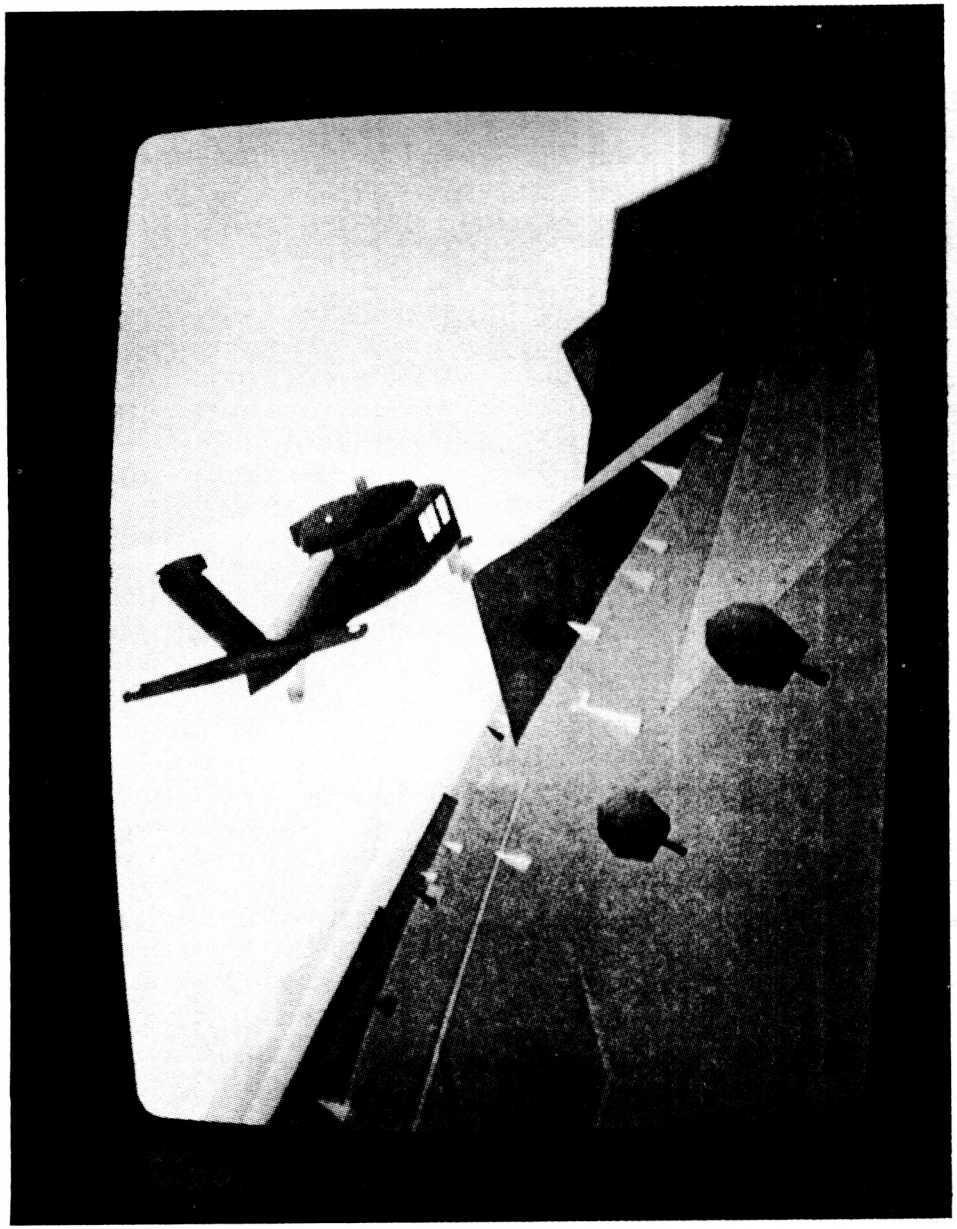
Air combat has been identified as a new role for Army rotorcraft to counter potential enemy high performance air-to-air helicopter threats. A major investigation was conducted on the Vertical Motion Simulator to develop a low-altitude air combat simulation capability and to probe desired maneuverability, handling qualities and flight control system characteristics.

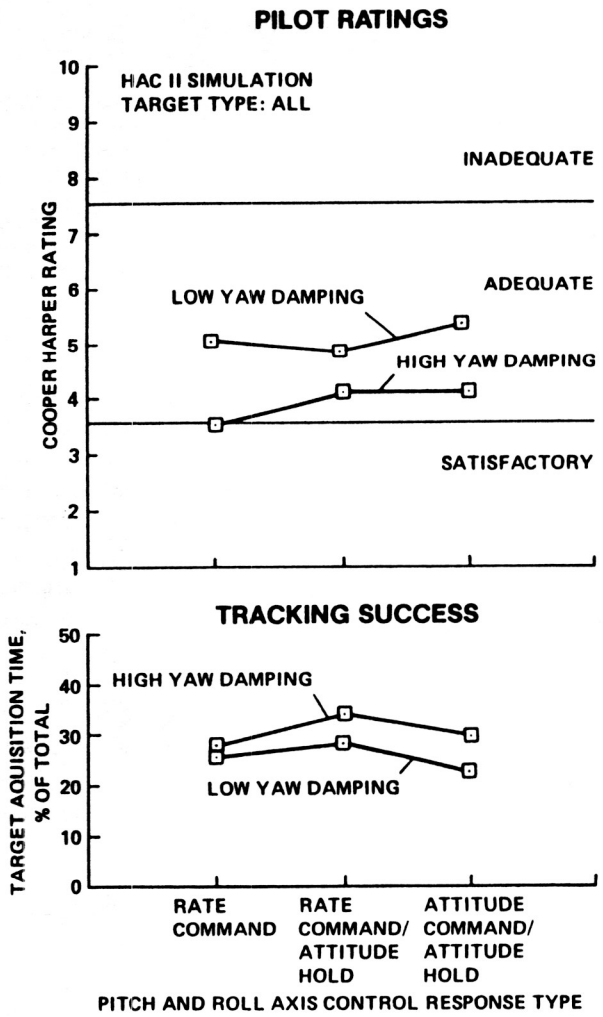
Experimental variables in the tests were the maneuver envelope size in terms of maximum load factor and sideslip angle, directional axis stability characteristics, and response type of the flight control system. Over 450 simulated air-to-air engagements were conducted by Army, NASA and industry pilots. Preliminary results from the tests indicate that a highly damped relatively directional response, low sideforce due to sideslip, and some effective dihedral were desired stability characteristics. A rate command system was favored over a pitch and roll attitude command flight control system in most situations, and an enhanced maneuver envelope size over that of current generation aircraft was found to be advantageous.

The simulation study provided a more thorough understanding of the requirements of an air combat task on rotorcraft capability and will allow the development of standards and systems to enhance the performance of future rotorcraft. Further work is planned in this area.

TECHNICAL CONTACT: Michael S. Lewis, ARC (415) 694-6115

ROTORCRAFT AIR COMBAT SIMULATION





Integrated Airframe/Propulsion Control System Architectures

The objective of the Integrated Airframe/Propulsion Control System Architectures program is to develop validation methodology so that efficient, complex, integrated airframe/propulsion control systems can be designed and implemented with confidence. The digital controller, both hardware and software, is the object of investigation, and how well it serves the computational needs and the operational needs of aircraft control are the criteria by which alternatives are judged.

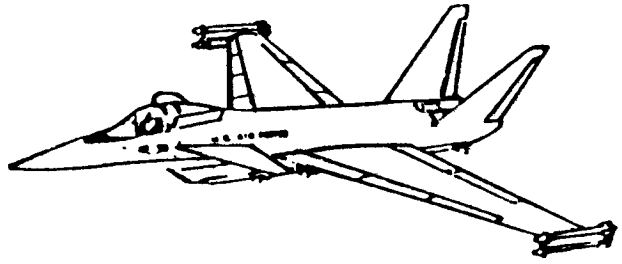
The maturing of digital control technology for aircraft has led to many proposals for active control of aircraft systems in order to provide performance that is unobtainable using passive structures. One established need is for the integrated control of the airframe, engine and inlet of high-performance aircraft. This integrated control task is the target application for the digital control system architectures investigation, and the airframe, engine and inlet control will be brought together and implemented using digital control technology. Suitable system architectures for these integrated control systems are as yet unknown, especially in regard to system reliability. Investigation of integrated airframe/propulsion control system architectures will provide guidance for the design of these systems and the more complex systems anticipated in the future.

Digital control system technology is now just able to cope with design and validation complexities using traditional design and testing methods. Baseline integrated airframe/propulsion systems have been devised using conventional individual control systems tied together in an ad hoc fashion. Integrated designs employing advanced technology show improvements in life cycle cost and reliability. With advanced technologies, a probability of failure less than 10^{-7} can be achieved. The initial effort has found a low sensitivity of life cycle cost to advanced architectural alternatives, but also found a concern in industry for the lack of technical capability to validate increasingly complicated digital control systems and a need and a potential to make significant progress in understanding the validation process. This initial work, which was a joint Langley/Lewis Research Center effort, has been carried out primarily by Lockheed California Company and Boeing Military Airplane Company.

The current effort, begun in late Fiscal Year 1985, seeks to develop an integrated design/validation process for an integrated airframe/propulsion control system. The test system will be used in the AIRLAB facility at Langley Research Center to experimentally demonstrate the integration process.

TECHNICAL CONTACT: Charles W. Meissner, Jr., LaRC (804) 865-3681

INTEGRATED AIRFRAME/PROPULSION CONTROL SYSTEM ARCHITECTURES



HIGH-PERFORMANCE AIRCRAFT

ELEMENTS

- RELIABILITY
- LIFE CYCLE COST
- ARCHITECTURE
- VALIDATION

TRADE STUDIES

CONCLUSIONS

- VALIDATION AN ISSUE
- 10^{-7} FAILURE RATE ACHIEVABLE WITH ADVANCED TECHNOLOGIES
- LIFE CYCLE COST IMPROVED
- ARCHITECTURE SELECTION TECHNOLOGY SENSITIVE

Advanced Automated Guidance Laws for High-Performance Aircraft

Recent advances in aircraft systems such as sensors and computers have made it feasible to implement sophisticated, complex guidance laws on-board aircraft. Although there has been much recent progress in developing and implementing guidance algorithms for automatic flight control of transports and other relatively low performance aircraft, fighter and attack aircraft continue to be primarily manually controlled by the pilot, for the following reasons. First, these high performance aircraft are capable of rapid, complex maneuvers and have complex mission objectives, making flight dynamics and performance analysis difficult. Second, the consequence both to the pilot and the aircraft of an improper maneuver is usually immediately catastrophic. Thus, it is likely that it will be many years before air combat is operationally completely entrusted to automated guidance algorithms. Nevertheless, recent progress in analysis of air combat maneuvering and recent advances in avionics systems indicate that automated air combat may eventually be possible and practical.

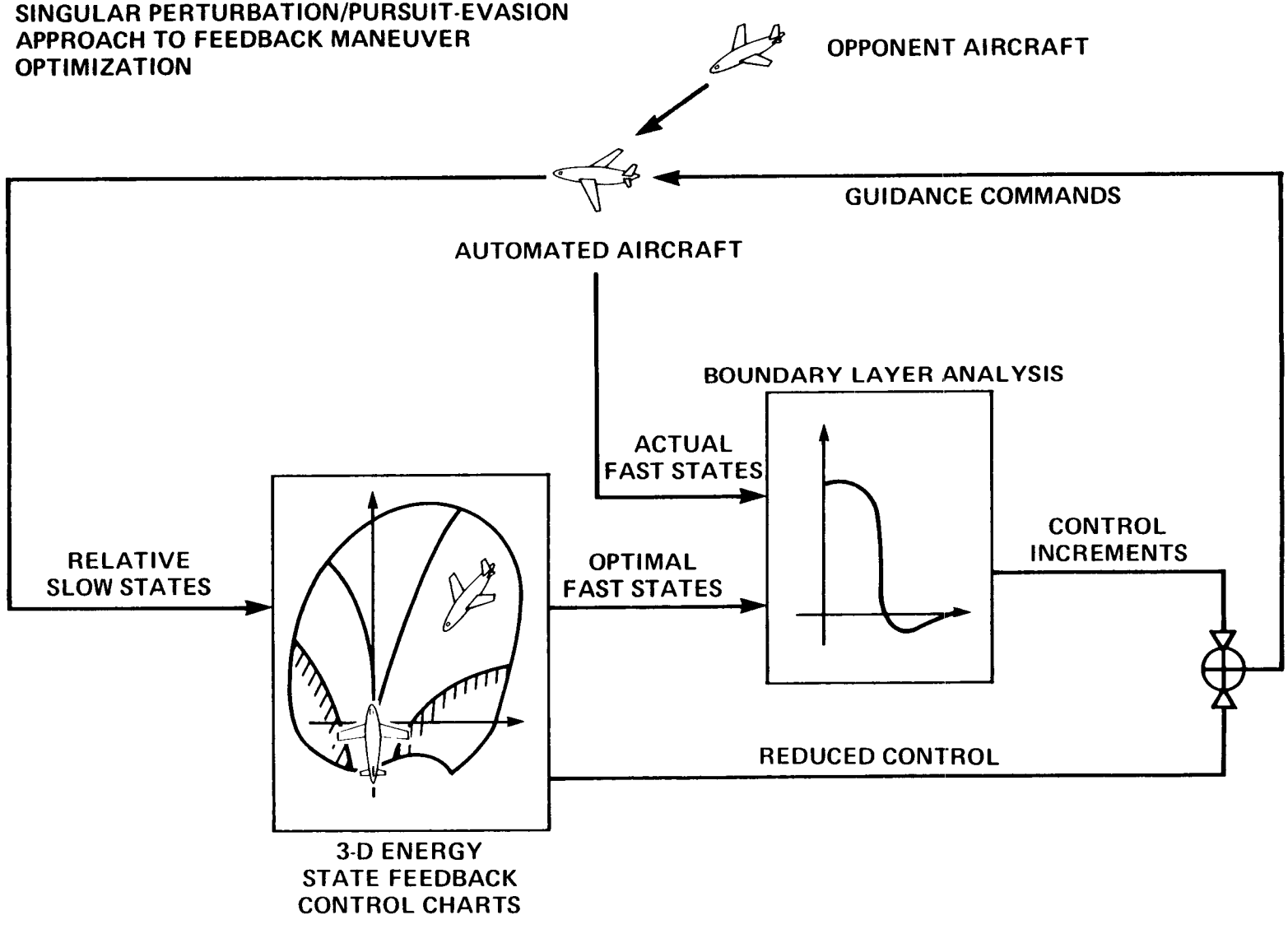
Three approaches to the development of automated air combat guidance laws are being pursued. In the first, singular perturbation methods are being combined with differential game theory. This approach enables solutions to be found to previously intractable pursuit-evasion problems. Considerable progress has been made in using these solutions to derive feedback control laws for real-time, on-board implementation, and these feedback control laws should be ready soon for validation by manned simulations and flight tests.

The second activity is basic research to develop a general and consistent mathematical theory of combat. A formulation of games of combat has been defined and work is in progress to develop computational methods for such games. The third activity involves artificial intelligence techniques which are being investigated for application to high-performance aircraft automation. Both heuristic and expert-system approaches are being developed for automation of aircraft control and other tasks. Although the differential game and artificial intelligence techniques are being developed more or less independently, in applications they will be combined as appropriate to provide an automated, intelligent system to either assist the pilot in a piloted aircraft or to control a pilotless vehicle.

TECHNICAL CONTACT: M. Ardema, ARC (415) 694-5450

ADVANCED AUTOMATED GUIDANCE LAWS FOR HIGH-PERFORMANCE AIRCRAFT

SINGULAR PERTURBATION/PURSUIT-EVASION APPROACH TO FEEDBACK MANEUVER OPTIMIZATION



Controls and Guidance - Space

The Space Controls and Guidance Research and Technology Program is directed toward enabling the next generation of space transportation systems, and large future spacecraft and space systems such as the growth Space Station, large communication antennas and high precision segmented reflector astrophysical telescopes. The new generation of transportation vehicles have demanding requirements placed upon them to provide for an order of magnitude reduction in cost as well as to provide for an increase in capability. The future orbital facilities have demanding control requirements for pointing and stabilization, momentum management, build-up and growth accommodation, and disturbance management.

To address these advanced transportation system vehicles requirements a research and technology program is being designed to provide the generic technology base to support the implementation of advanced guidance, navigation, and control (GN&C). This technology has the capability to provide for a large reduction in both the number of people who plan and generate the mission software and people necessary later to provide for mission control. Additionally, this technology has the profound capability to impact vehicle design concepts by making the GN&C specialist an equal partner with the aerodynamicist, materials and structures engineer, and propulsion engineer in interactions with the systems engineer. The activity in this area will build on the adaptive GN&C research and technology plan generated in FY85 for an atmospheric orbital transfer vehicle.

To address future orbital facilities requirements, an advanced technology program is underway in system identification, distributed control, integrated controls/structures design methods, and advanced sensors and actuators. Because the behavior of large, light weight per unit area deployable/assembled spacecraft is greatly influenced by the ground environment (principally gravity), the testing and verification activity is both ground- and space-based.

Promising controls approaches and algorithms will be tested in space under NASA's Control of Flexible Structures (COFS) Program on a Shuttle-attached long flexible beam facility especially designed as a controls research test article. This facility is intended as a national facility; therefore, it is being made available to university professors, other government agencies, and industry researchers and industry IR&D program managers to develop and test control algorithms.

PROGRAM MANAGER: John D. DiBattista
NASA/OAST/RC
Washington, DC 20546
(202) 453-2750

Control of Flexible Structures (COFS) Flight Experiment Program

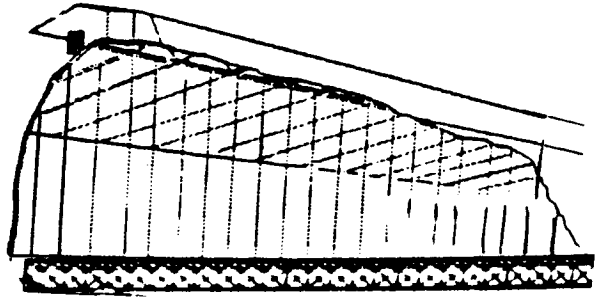
The Control of Flexible Structures (COFS) Flight Experiment Program consists of a unified analysis and modeling ground experiment and a series of Shuttle-attached experiments specifically designed to systematically evaluate NASA, industry IR&D, university and other government agencies' algorithms and techniques for on-orbit systems identification and flexible body control of large flexible structures. This program will serve to validate the enabling technologies for future NASA missions such as the evolutionary Space Station and large orbital antennas.

The COFS 1 test article, a 1-dimensional structure, is a joint-dominated, deployable truss beam 60 meters in length with a 1.2 meter triangular cross section. The beam is sufficiently large and flexible to make the validity of full-scale ground testing questionable. The frequency of the first bending mode is approximately 0.2 Hz, and mechanisms are provided to vary the frequency spacing and cross axis coupling to provide closely-spaced and geometrically-coupled modal pairs. System identification sensors are distributed along the beam, and multi-axis control actuators are provided at various locations. The COFS structure is excited by beam-mounted actuators and the Shuttle Reaction Control System (RCS) and dynamic characterization data are accumulated from which processing identifies the mode shapes, frequency, and natural structural damping. Co-located and distributed control algorithms are incorporated in the flight computer to support active damping of the excited beam, beam shape and tip position control using flexible body control laws employing several sensor sets and actuator sets.

The COFS 2 test article is a 3-dimensional structure similar to the large offset antenna shown. This test article adds to the complexity of maintaining the shape of a precision surface and boom structure. For both test articles system identification algorithms are incorporated in the flight computer to support adaptive control experiments. This will validate control of the conditions of time-varying model characteristics or erroneous initial predictions of modal characteristics. Individuals and organizations desiring to use COFS in their research are encouraged to call or write the technical contact.

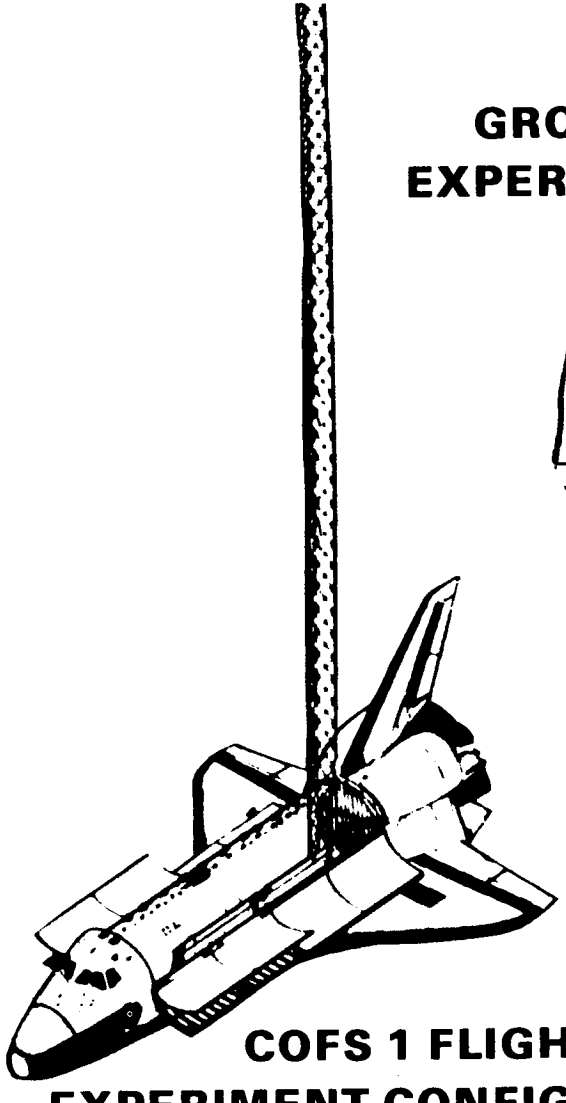
TECHNICAL CONTACT: Anthony Fontana, LaRC (804) 865-4591

CONTROL OF FLEXIBLE STRUCTURES

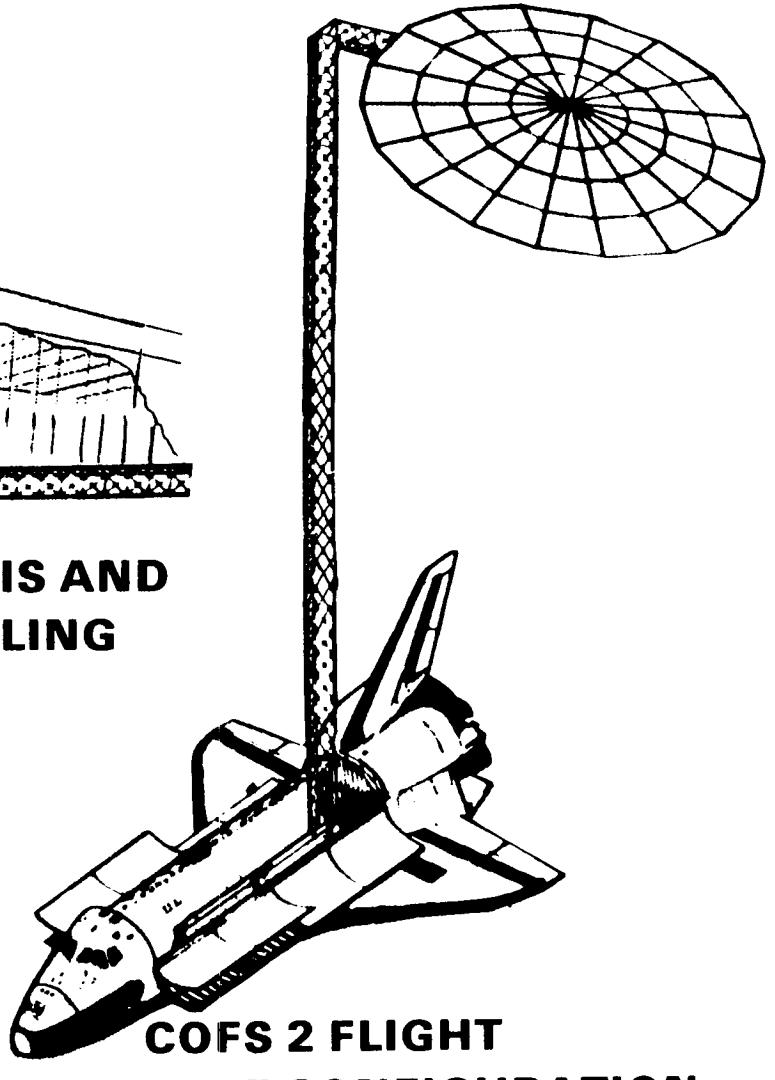


GROUND EXPERIMENTS

ANALYSIS AND MODELING



COFS 1 FLIGHT EXPERIMENT CONFIGURATION



COFS 2 FLIGHT EXPERIMENT CONFIGURATION

Spacecraft Control Laboratory Experiment

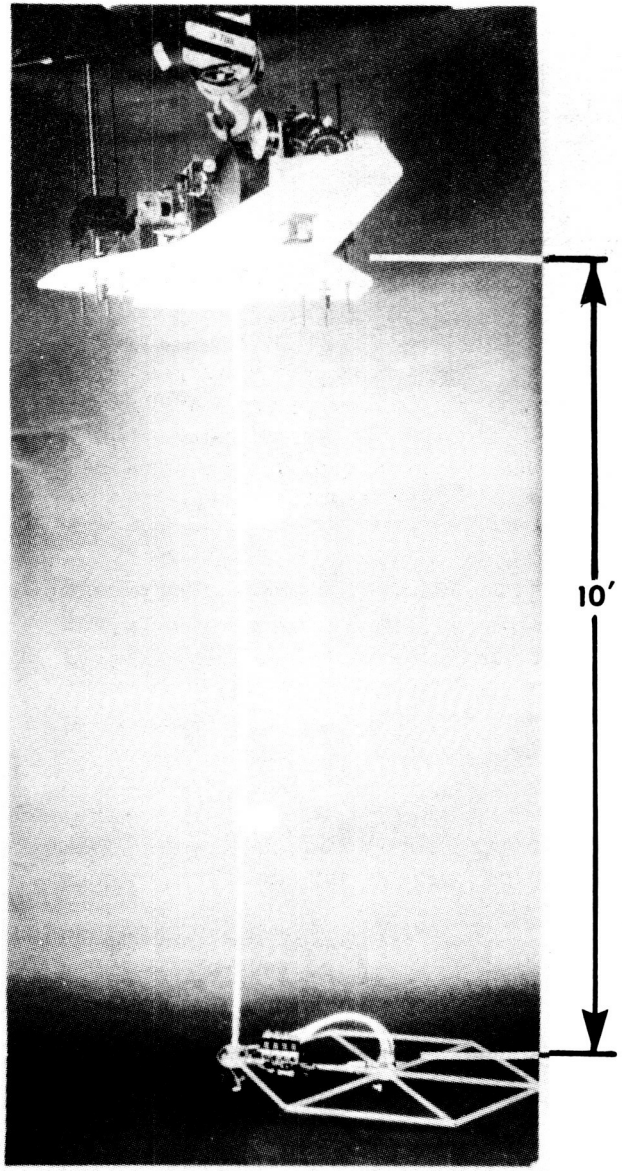
The Spacecraft Control Laboratory Experiment (SCOLE) will allow direct experimental comparison of competing control schemes for large flexible space structures. The experiment has been designed to emulate the essential characteristics of a mathematical model "design challenge" which represents a Shuttle Orbiter having a flexible mast and antenna attached. This experiment is the third in a series of increasingly more difficult flexible structure control experiments performed by the Guidance and Control Division at Langley Research Center. The key problem addressed by the experiment is that the flexible motion of the mast and antenna must be considered in the slewing and pointing control problems.

The three-dimensional control problem is facilitated by suspending the Shuttle body from its center-of-gravity by a three-degree-of-freedom ball joint on a ten foot cable (see opposite figure). This fixture allows free rotation about three axes and pseudo translation in the horizontal plane. The basic complement of control system components will be the same for all control schemes. This includes three-axis torque on the Shuttle body, a pair of two-axis torquers on the mast, two-axis torque on the antenna end of the mast, and two-axis force at the center of the antenna. Sensors will consist of three-axis angular rate and linear acceleration on the shuttle body, five sets of two-axis accelerometers on the mast, three-axis angular rate at the antenna end of the mast, and two-axis acceleration at the center of the mast.

The computer system consists of a 32-bit microprocessor based CPU which is programmable in the C and Fortran languages. Data acquisition and actuator commands are accomplished with 12-bit analog-to-digital and digital-to-analog converters. Eight serial lines are also available to communicate with a distributed set of microcontrollers. These may be used to investigate "smart" sensor and actuator technology, or to perform some of the control law processing which would normally be done in the CPU.

TECHNICAL CONTACT: L. W. Taylor, LaRC (804) 865-4591
J. P. Williams, LaRC (804) 865-4591

SPACECRAFT CONTROL LABORATORY EXPERIMENT (SCOLE)



TESTBED FOR EVALUATION OF CONTROL TECHNIQUES FOR FLEXIBLE SPACE STRUCTURES

- VALIDATED TECHNIQUES WILL BE APPLICABLE TO ANTENNAS AND FLEXIBLE SPACE STATION
  - 3-D CONTROL PROBLEM WITH 12 ACTUATORS AND 30 SENSORS
    - EXPERIMENT HARDWARE 90% COMPLETE. OPERATIONAL CAPABILITY USING ANALOG AND DIGITAL COMPUTERS HAS BEEN DEMONSTRATED

Ground Facility for Large Space Structure Control Verification (GS/LSSCV) - Test Configuration 1

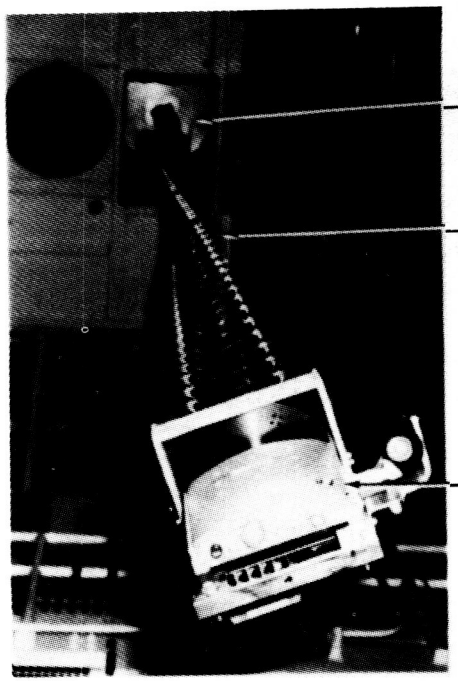
Marshall Space Flight Center has developed a facility in which closed loop control of Large Space Structures (LSS) can be demonstrated and verified. The main objective of the facility is to verify LSS control system techniques so that on-orbit performance can be ensured. The facility consists of an LSS test article which is connected to a payload mounting system that provides control torque commands. It is attached to a base excitation system which simulates disturbances most likely to occur for Orbiter and DoD payloads. A control computer will contain the calibration software and the control algorithms. The total system is suspended in such a fashion that the LSS test article has the characteristics common to all LSS's.

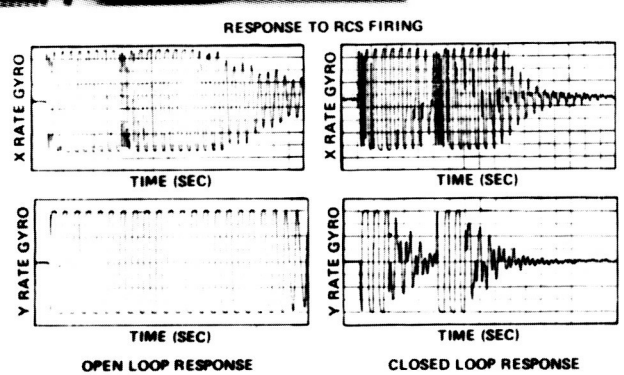
In its present configuration, the LSS test article has a four meter cruciform attached to its lower end which lowers and compresses the system modes, couples the lateral and torsional modes, and adds low frequency local modes, thus providing 12 vibration modes below 2 Hz. The accelerometer/rate gyro packages at both ends of the structure along with the three gimbal torque motors will permit both centralized and decentralized digital control experiments of the following types: classical frequency response methods, pole placement algorithms, observers/estimators, and linear quadratic regulators.

An end-to-end system checkout has been performed on this configuration with a centralized pole placement algorithm which provides direct authority over four system modes while increasing the damping of the remaining modes. The successful system checkout also verified the analytical modeling and simulation methods, which will become increasingly important in future LSS experiments.

TECHNICAL CONTACT: Harry Buchanan, MSFC (205) 453-4582

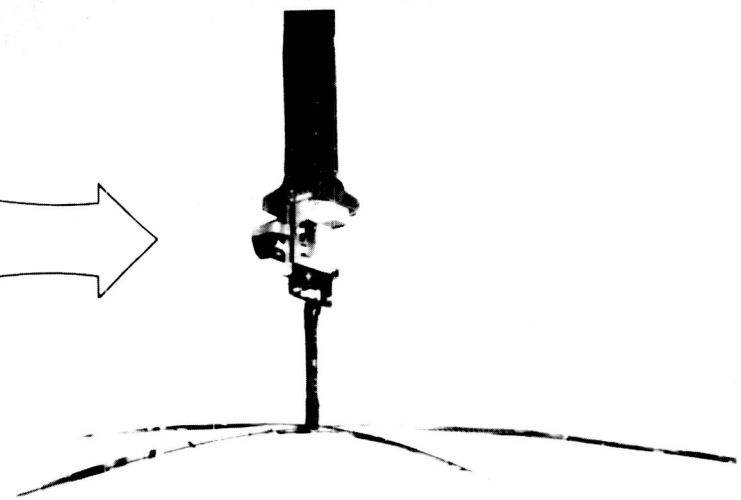
STRUCTURES/CONTROLS TEST CONFIGURATION 1





SIGNIFICANCE

- GENERIC CONTROL/FLEXIBLE STRUCTURE INTERACTION TEST CAPABILITY



4 METER CRUICIFORM

RESULTS

- COUPLES LATERAL & TORSION MODES
- ADDS LOW FREQUENCY LOCAL MODES

Ground Facility for Large Space Structure Control Verification (GF/LSSCV) - Test Configuration 2

The next configuration planned for the GF/LSSCV features a flexible antenna-like structure mounted in place of the cruciform used in Test Configuration 1. A two axis reactionless steering mirror mounted at the other end of the test article will be used to investigate Image Motion Compensation techniques by redirecting a laser beam from a reflecting mirror at one part of the antenna to a detector at an opposing location. Vibration suppression will be enhanced with the addition of linear, bi-directional cold gas thrusters at the antenna end of the structure. Distributed control techniques will be investigated with the addition of Linear Momentum Exchange Devices (LMEDs) at various locations along the Astromast. The LMEDs will be provided by the Air Force as part of their Active Control of Space Structures (ACOSS) program.

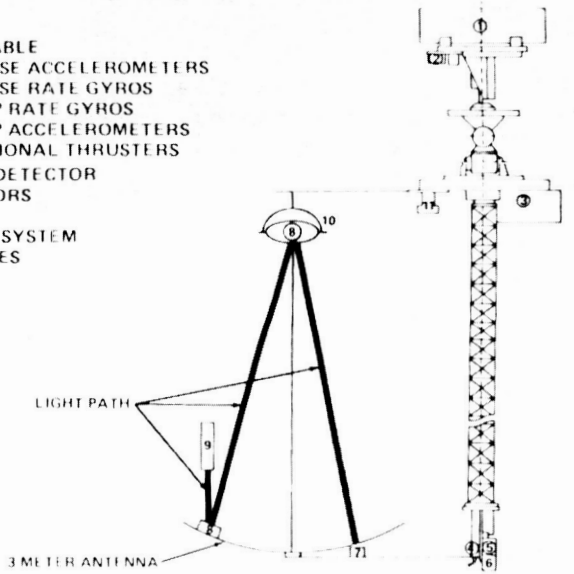
Opportunities for industry participation will be provided in the evaluation of disturbance isolation control techniques such as model error sensitivity suppressing, model reference adaptive control, maximum entropy/optimal projection, and high authority/low authority control integration. Future configurations under consideration include use of the SAFE-I boom for preliminary Pinhole/Occulter Facility investigations, and large angle, flexible multibody experiments.

TECHNICAL CONTACT: Harry Buchanan, MSFC (205) 453-4582

STRUCTURES/CONTROLS TEST FACILITY CONFIGURATION 2

EXISTING
1. SHAKE TABLE
2. 3 AXIS BASE ACCELEROMETERS
3. 3 AXIS BASE RATE GYROS
4. 3 AXIS TIP RATE GYROS
5. 3 AXIS TIP ACCELEROMETERS

ADDED
6. BIDIRECTIONAL THRUSTERS
7. OPTICAL DETECTOR
8. REFLECTORS
9. LASER
10. 2 GIMBAL SYSTEM
11. N_2 BOTTLES



TECHNIQUES TO BE DEMONSTRATED

- ACTIVE IMAGE MOTION COMPENSATION
- VIBRATION CONTROL VIA LINEAR THRUSTERS
- EVOLUTIONARY CONTROL
- CLOSED LOOP PARAMETER ESTIMATION/CONTROL

System Identification

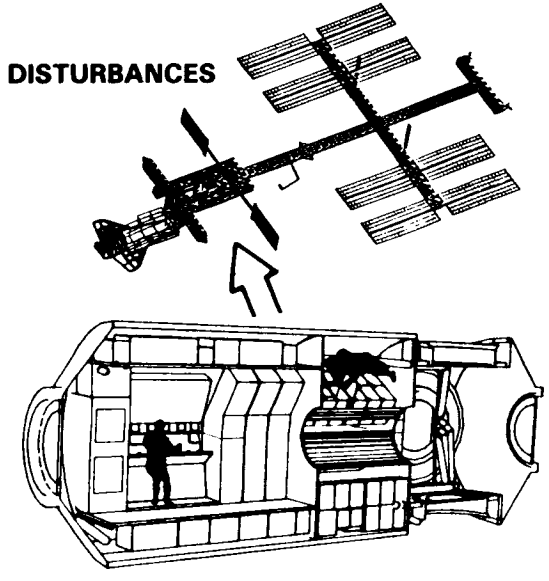
The objective of this program is to develop self-contained software modules and design criteria for potential use of identification technology on emerging large, flexible spacecraft, particularly the Space Station and large antennas. Control performance for these space systems will be sensitive to modeling errors such as truncated dynamics, parameter errors, and neglected nonlinearities. Since these space systems are planned for assembly and growth on orbit, neither ground test nor a priori analysis can completely determine the effects of model error on performance or insure that adequate control margins are designed to account for dynamic effects during system lifetime. During the mission, any control system data analysis function wil require an in situ subsystem to monitor control performance during disturbance or system change, and through this performance, to determine parameters which adapt controllers to the new control environment.

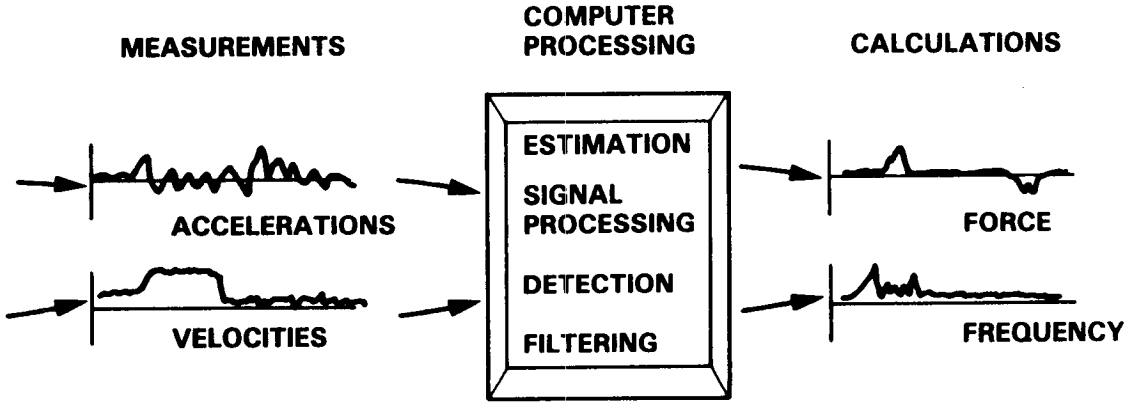
New technology is required for the following tasks: to synthesize flight-qualified subsystem level identification capabilities; to develop fast, numerically stable algorithms which handle large scale models and optimally use operationally limited data samples; to use spatially distributed sensors and actuators; and to develop architectures which accommodate parallel processing and autonomy. As the opposite figure example of crew disturbance identification indicates, technologies in these areas must be integrated in performing the identification function.

In FY 85, activities focused on: integrating probabilistic detection, fast filtering and smoothing of data from spatially distributed systems in the reconstruction of disturbance time histories; on-line determination of an event time window of data for use in model parameter identification; linear regression strategies for the identification of mass and spacecraft control environment disturbance properties; and proof-of-principle evaluation with typical large structure models. Future work will involve development of design criteria and strategies for use of sensors and excitation schemes in identification; applications to proof-of-principle physical experiments; and evaluation through extensive ground simulation. Results of these activities will further the development of the requirements, processing architecture, and application of identification subsystems.

TECHNICAL CONTACT: Fernando Tolivar, JPL (818) 354-6215
Jacob Matijevic, JPL (818) 354-6077

SYSTEM IDENTIFICATION





PAYOFFS

- ENABLES LARGE SPACE STRUCTURE CONTROL
- AUTOMATES PERFORMANCE MONITORING
- AUTOMATES TUNING OF CONTROLLERS, ACCOUNTING FOR CONFIGURATION OR OPERATIONAL CHANGES

ACCOMPLISHMENTS

- OPERATIONAL DISTURBANCE DETECTION AND TIME HISTORY RECONSTRUCTION
- CONTROL/STRUCTURES MODEL PARAMETER IDENTIFICATION

Nonlinear Simulation and Modeling

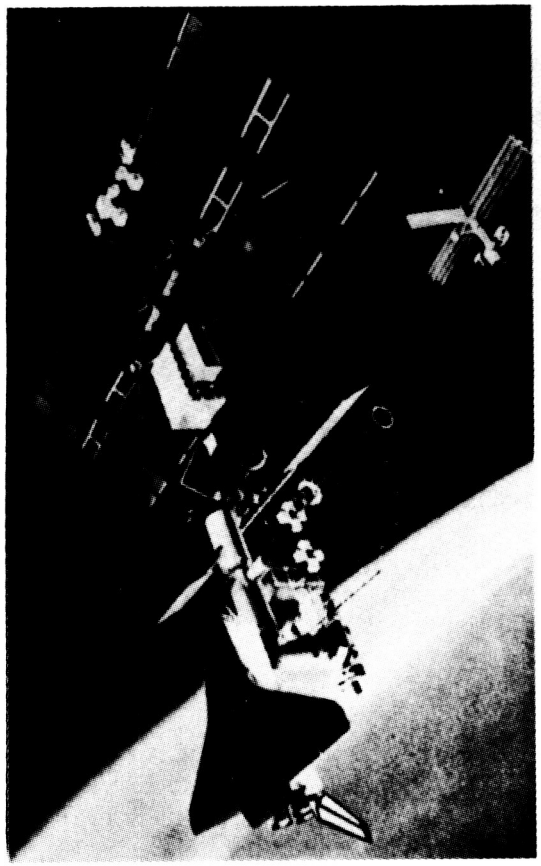
Accurate modeling and simulation of complex flexible spacecraft is a prerequisite for the design and verification of LSS control systems. The Augmented Flexible Body Dynamic Analysis Program, a cooperative effort by NASA/MSFC and Honeywell, Inc., has developed a time history simulation program called TREETOPS which provides the control system engineer with an analysis and design tool for arbitrary, point connected, flexible bodies in a tree topology.

The nonlinear multibody dynamics are formulated via Kane's method of generalized speeds, which automatically eliminates any constrained degree of freedom. Structures are modeled on a component mode basis and connected by articulated joints, with up to six degrees of freedom, which permit large angular rotations and rates. The use of component modes allows for rapid reconfiguration and reduced order modeling via augmented mode shapes. Control algorithms can be implemented with TREETOPS' analog or digital linear control packages or by interfacing with arbitrary user-defined controller subroutines. A linearization option is also provided for multivariable controller designs. TREETOPS has been employed at MSFC for the Space Telescope, Spacelab Instrument Pointing System and Infra-Red Telescope, Space Station Attitude Control and Reboost, and the Ground Facility for Large Space Structure Control Verification.

TREETOPS is currently being evaluated by over 13 other government agency or industry users who have shown interest in its potential applications. The program is still under development, and enhancement features are being added which will allow closed topologies, nonholonomic constraints, orbital dynamics and disturbances, and model reduction facilities.

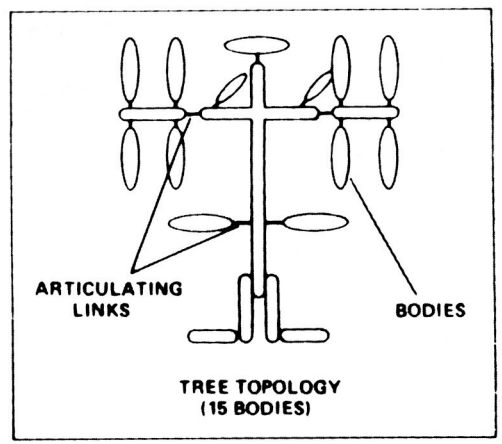
TECHNICAL CONTACT: Harry Buchanan, MSFC (205) 453-4582

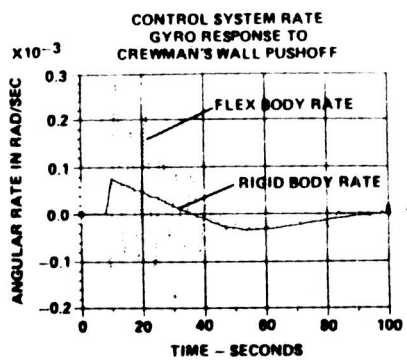
NON-LINEAR SIMULATION AND MODELING



SIGNIFICANT FEATURES

- MODULAR CONCEPT ALLOWS RAPID RECONFIGURATION
- MODELS LARGE ANGLE ROTATIONS OF APPENDAGES
- CHAIN, TREE AND RING TOPOLOGIES HANDELED
- VARIETY OF CONTROL MODULES AVAILABLE





Unified Control Structure Modeling and Design

The current approach for dealing with flexibility issues in spacecraft control system design is based on obtaining sufficient frequency separation between the control system and the dominant structural frequencies, and the selective elimination of the few remaining frequencies that cannot be so separated. This design luxury will not be available in many future spacecraft, where there may be many closely packed low frequency modes that interact with the control system.

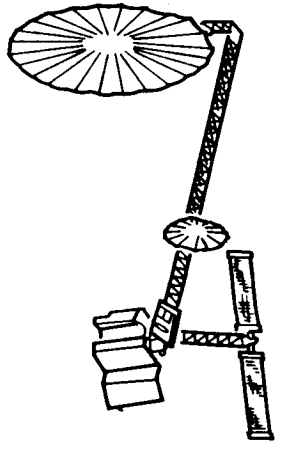
The Unified Control Structure Modeling and Design program is specifically defined to address the theoretical issues associated with the practical implementation of control systems for large flexible spacecraft having the features discussed above. The ultimate program goal is the development of a computer-aided design package for modeling and control design that incorporates elements from distributed parameter systems theory, control-driven modeling, model reduction methodologies, and robust control design methods. This package is envisaged to enable the designer to develop control systems that satisfy the multi-objective criteria that are imposed in an operational setting, e.g., accommodation of model truncation, parameter errors, actuator/sensor bandwidth limitations, finite computer memory size and computational overhead constraints.

Work has thus far focused on the development and validation of algorithms and software that will comprise specific components of the final computer-aided design package. Software has been devleoped that simultaneously produces a control system design/structure model pair that minimizes potential spillover instabilities induced by model truncation. A compensator reduction package has been developed that reduces computational overhead in real time implementation. Most recently, enhancement methods to accommodate structure parameter error have been investigated. Each of these components has been tested in proof of principle simulations on a large order flexible antenna model (see opposite figure).

TECHNICAL CONTACT: Fernando Tolivar, JPL (818) 354-6215
M.H. Milman, JPL (818) 354-7548

UNIFIED CONTROL STRUCTURE MODELING AND DESIGN

TARGET APPLICATION



KEY CHALLENGES

- STRINGENT POINTING REQTS
- ROBUST OPERATION
- RESOURCE/COMPLEXITY CONSTRAINTS

PERFORMANCE OBJECTIVES

- POINTING
- JITTER
- STABILITY

PERFORMANCE CONSTRAINTS

- MODEL TRUNCATION
- PARAMETER ERROR
- HARDWARE/SOFTWARE BANDWIDTH

DESIGN METHODOLOGIES

- CONTROL DRIVEN MODELING
- DISTRIBUTED PAREMETER CONTROL THEORY
- MODEL REDUCTION
- LOOP RECOVERY/SHAPING
- SENSITIVITY OPTIMIZATION

UNIFIED CONTROL LAW

PAYOFFS

- AUTOMATION OF DESIGN PROCEDURE
- REDUCED DESIGN COSTS
- INCREASED SYSTEM PERFORMANCE
- INCREASED SYSTEM ROBUSTNESS

ACCOMPLISHMENT

DEMONSTRATED DESIGN METHODOLOGY THAT ADAPTS TO SYSTEM OBJECTIVES AND CONSTRAINTS

Spatial, High Accuracy, Position-Encoding Sensor (SHAPES)

As spacecraft size increases, more sophisticated control systems are required to maintain position, attitude and control shape and vibration of extended structures. These control systems, in turn, give rise to a need for sensors which can make rapid measurements of the three dimensional position of many points simultaneously at rates high enough for use by the control systems.

The SHAPES concept combines recent developments in fast laser diodes with established techniques in the areas of fiber optics, integrated optics, streak tubes, picosecond optoelectronics, and charged coupled device (CCD) detectors into a system which measures the three-dimensional coordinates of many points distributed in space at rates high enough for control functions. A stream of pulses from a laser diode is directed to reflective targets. The measure of the range is provided by a comparison between the time of return of the pulses from the targets with the time of arrival of a reference pulse. This comparison is made with a streak image-converter tube whose output is detected by a CCD. Angular positioning of the targets is determined by a second CCD which detects the direct images of the target reflectors.

The expected performance of the SHAPES system (see opposite figure) can be summarized as follows: the accuracy of the angular measurement with full field optics is one part in 10^5 (with the addition of an "image combiner" of coherent fiber-optic bundles, this becomes approximately one part in 10^4); the range measurement uncertainty is about 0.1 mm; and the number of targets can be as high as 50 and the data range from 1 to 10 target sets per second.

A series of development experiments is underway. Current efforts are directed towards demonstrating ranging to an array of moving targets actuated to simulate the vibrational motion of a large structure such as an antenna. New circuits have been developed to extract range information from the CCD output in real time and compact, efficient actuators have been developed to drive the test targets in sinusoidal motion with amplitudes as large as 4 cm at 1 Hz and to 10 Hz at lower amplitudes.

TECHNICAL CONTACT: Fernando Tolivar, JPL (818) 354-6215
John M. McLauchlan, JPL (818) 354-6631

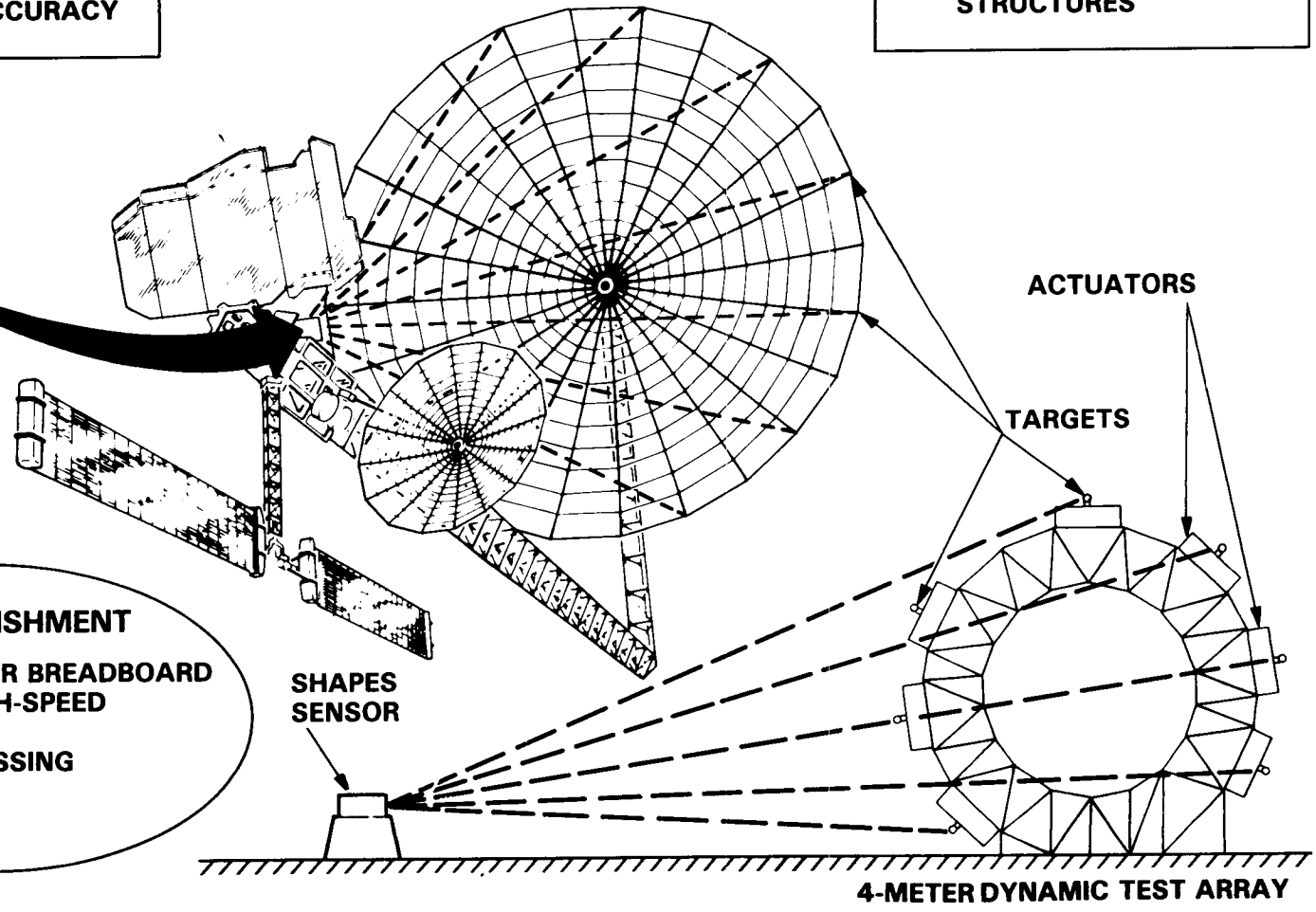
SHAPES: SPATIAL HIGH-ACCURACY, POSITION-ENCODING SENSOR

CAPABILITY GOALS

50 TARGETS
1 - 200 METER RANGE
3-D LOCATION
TO ±0.1 MM ACCURACY

PAYOFF

STATIC SHAPE AND DYNAMIC CONTROL OF LARGE STRUCTURES



ACCOMPLISHMENT

SHAPES SENSOR BREADBOARD WITH NEW HIGH-SPEED MULTI-TARGET SIGNAL PROCESSING ELECTRONICS

Automated Adaptive Control Subsystem

Control performance for future spacecraft such as space stations and manned space platforms are sensitive to modeling uncertainties, measurement errors, and actuator time delays. Space construction, in-orbit assembly, and proximity and docking operations add substantial difficulties to the control system. Adaptive control for the above systems offers significant performance benefits and for many cases, is enabling. The objective of this technology program is to develop autonomous adaptive control algorithms and mechanization concepts that are insensitive to system hardware constraints, model parameter uncertainites, truncated dynamics and time varying effects for stabilization control and performance enhancement of emerging large flexible space systems.

Adaptive control is a high gain system. Under extreme conditions, such as the high dynamic load transients which occur during Shuttle docking operations, the demands on control can far exceed the hardware capability. Control with reduced actuation effort is not only desirable but also necessary. The scope of this task includes the treatment of broad implementation issues and the development of numerical algorithms for real time processing.

The progress in FY 85 focused on the development of advanced adaptive control concepts and designs that utilize inflight dynamics information. Two sets of global stability conditions have been developed for adaptive control of flexible structures. Extensive computer simulations for proof-of-concept performance evaluation have been carried out for two Space Station configurations involving operations of both initial build-up and operational systems (see opposite figure). Future work will be focused on the ground experiment definition and design and robust algorithm development.

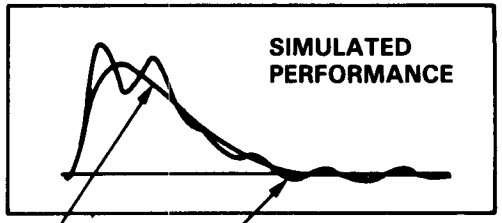
Technical results are documented in (1) "Dynamic Modeling and Adaptive Control for Space Stations," JPL Publication No. 85-57, July 15, 1985; (2) "An Investigation of Adaptive Control Techniques for Space Stations," 1985 American Control Conference, June 1985, Boston, pp. 81-95; (3) "Application of Adaptive Control to Space Stations," 1985 AIAA Guidance, Navigation and Control Conferences, August 1985, Snowmass, Colorado, pp. 709-724; all by C.H.C. Ih and S.J. Wang.

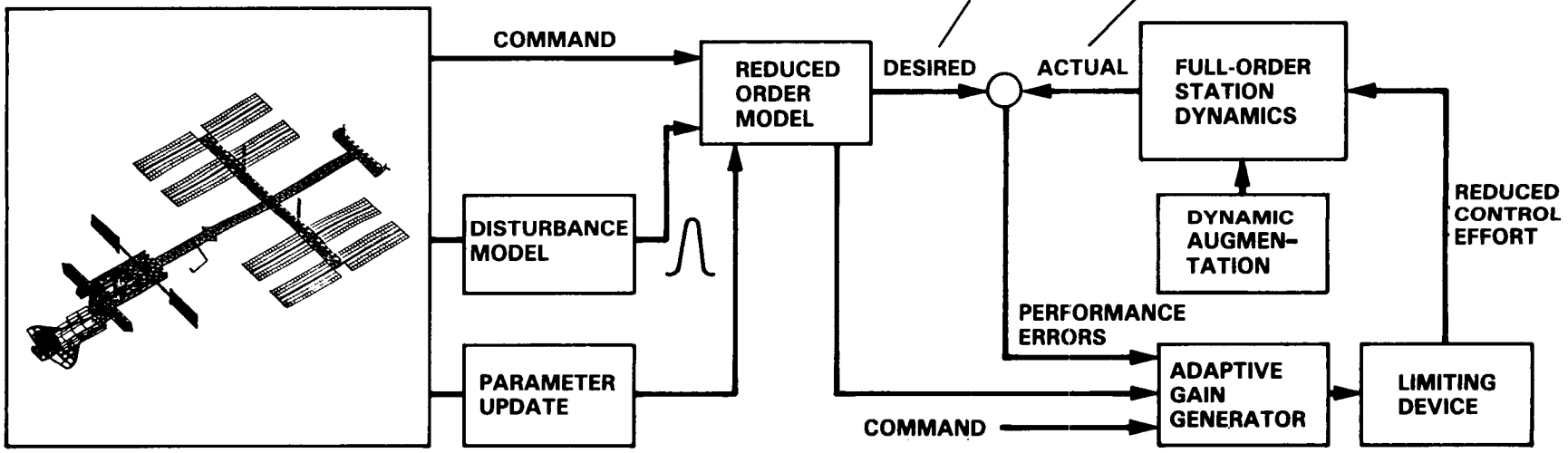
TECHNICAL CONTACT: Fernando Tolivar, JPL (818) 354-6215
Shyh J. (Don) Wang, JPL (818) 354-7288

AUTOMATED ADAPTIVE CONTROL SUBSYSTEM

the

GOAL:
ROBUST AUTOMATED ADAPTIVE CONTROLLER FOR LARGE FLEXIBLE SPACECRAFT





- DOCKING
- ASSEMBLY
- ARTICULATION
- MEN-MOTION

ACCOMPLISHMENT

- DEVELOPED AN ADAPTIVE CONTROLLER FOR FLEXIBLE SPACE STRUCTURES
- DEMONSTRATED PERFORMANCE BENEFITS THROUGH COMPUTER SIMULATION

Advanced Precision Pointing Technology

Large flexible base vehicles such as Space Station will present articulated payload pointing system designers with two significant challenges: an unprecedented level of dynamic disturbances and a set of extremely low frequency base vehicle structural modes (e.g., 0.1 Hz for Space Station). The former challenge represents a quantitative change over current systems; the latter a qualitative change, since for such systems it will be impossible to maintain the traditional separation between structural frequencies and pointing control bandwidth. Conventional gimbal-based pointing systems, which achieve payload articulation by reacting against the base vehicle, will be heavily taxed to avoid inducing structural instabilities in the presence of such an environment. Achieving a high level of pointing performance is beyond reach without incorporation of a highly sophisticated, system specific controller.

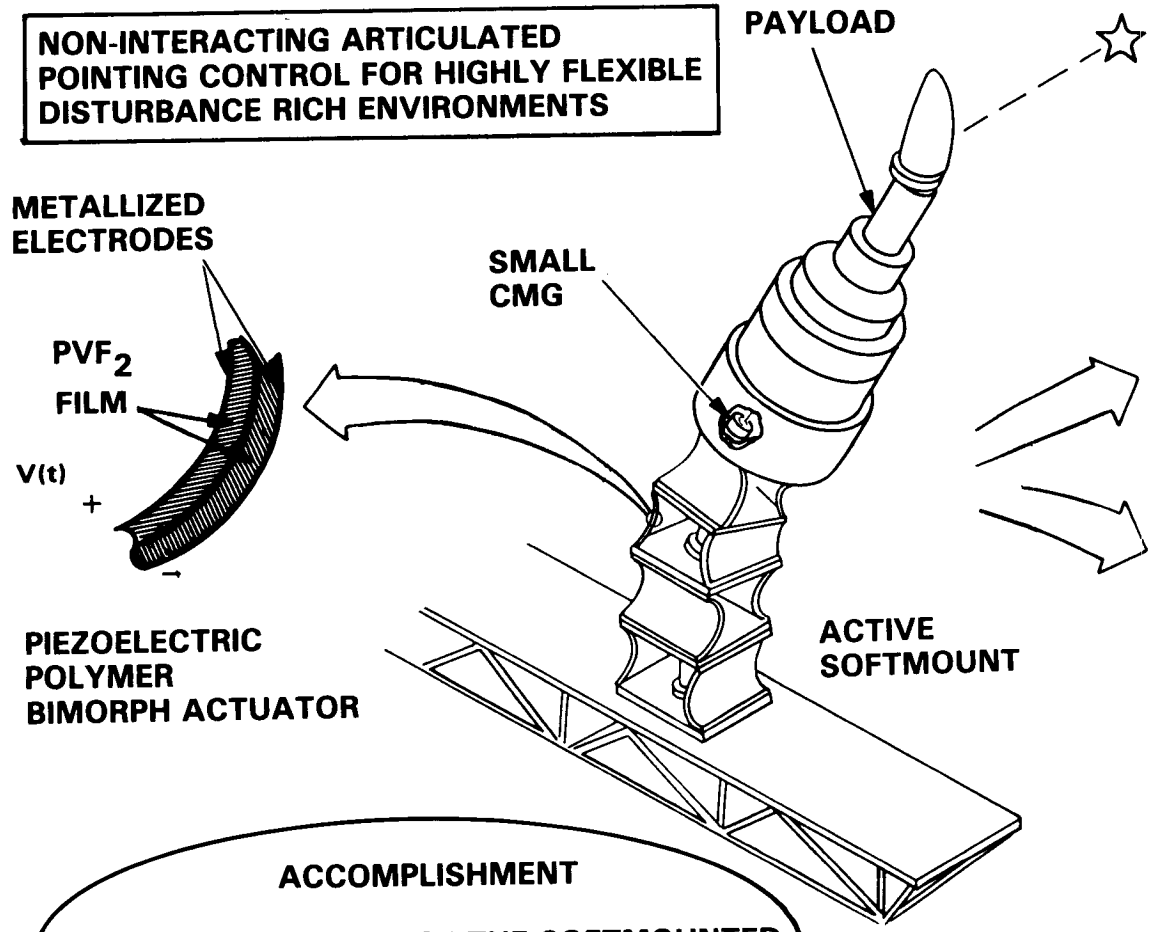
The above considerations motivate the development of a pointing concept that incorporates a mechanically soft (but actively controlled) interface between payload and base vehicle with primary pointing control authority resident on the payload in the form of a reaction wheel or control moment gyro. Such an approach provides two way isolation between payload and basebody, mitigates the problem of control bandwidth (structural frequency interaction accomplishes payload "stationkeeping"), and enables a modular design approach applicable to a wide range of prospective payloads. The principal accomplishment of FY 85 was the conceptual design of such an active "softmount" pointing system (see opposite figure). The concept incorporates the use of the piezoelectric polymer PVF_2 to implement the soft active interface.

The softmounted inertially reacting pointing concept, using an active PVF_2 based softmount, will be pursued towards a six degrees of freedom analytical proof of concept in FY 86. Breadboard development and test will follow.

TECHNICAL CONTACT: Fernando Tolivar, JPL (818) 354-6215
Robert A. Laskin, JPL (818) 354-3690

ADVANCED PRECISION POINTING TECHNOLOGY

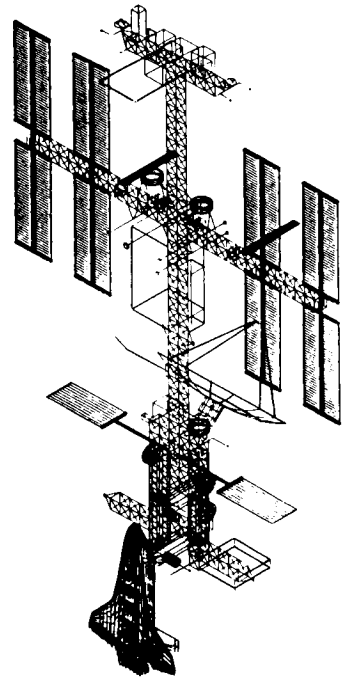
NON-INTERACTING ARTICULATED POINTING CONTROL FOR HIGHLY FLEXIBLE DISTURBANCE RICH ENVIRONMENTS



PAYOFFS

DECOUPLED DYNAMICS ALLOWS DECOUPLED CONTROLS DESIGN

- **SIMPLICITY**
- **MODULARITY**
- **GUARANTEED STABILITY**



ACCOMPLISHMENT

CONCEPTUAL DESIGN OF THE SOFTMOUNTED INERTIALLY REACTING POINTING SYSTEM

Construction/Docking Technology

Future space operations will include a variety of activities requiring the mating of two or more bodies, such as the construction of large space structures and docking or berthing the Shuttle Orbiter to the Space Station. Many applications will require very low levels of transferred energy between vehicles during the docking/berthing operation. Some will require automated or remote-controlled rendezvous and joining, crew and/or equipment transfers, inspection and servicing.

The primary objective of this program is to develop the required technology for "soft" docking or berthing systems and to advance component state-of-the-art to achieve desired system results. These objectives were to be met by the design and development of a full-scale prototype docking/berthing system and its test in the JSC Docking Test Facility. This plan has been modified because of budget constraints by delaying system fabrication and testing. Immediate goals will be to develop concepts for attaching docking/berthing systems to space vehicles, provide adequate attenuation and flexibility in docking/berthing systems, provide simulation software to analyze the effects of system design changes and docking parameters on the docking/berthing process, develop controllable electromechanical actuator/attenuators (EMAAs) to prealign the docking/berthing interfaces to reduce energy transfer, ensure capture, attentuate energy during the docking process, and to identify components to be made from composite materials to reduce system weight and cost.

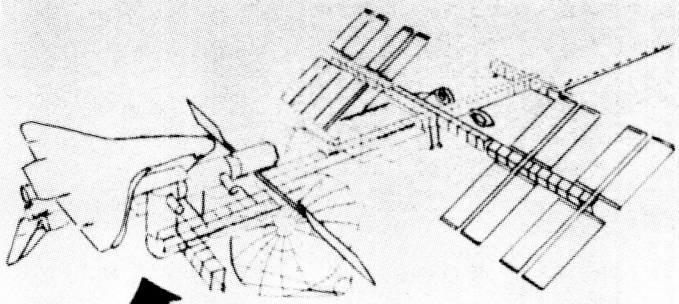
Primary accomplishments during FY 85 are numerous and varied. Technology developed as a result of this study was shared with the Space Station Program Office and has formed the basis of current program and contractor docking/berthing requirements and designs (see opposite figure). The analytical program, SOFTDOCKSIM, has been translated into VAX FORTRAN 77 and enhanced to reduce disk space, CPU and operator time requirements. Orbital mechanics were included to provide better results, and interfaces were defined to use System Engineers Simulator (SES) proximity operations data as the initial conditions for SOFTDOCKSIM runs.

Advanced digital and position controllers were developed for the prototype EMAA. Design and implementation of a positioning/velocity/acceleration digital controller is progressing to allow programming of specific attenuation profiles for the EMAA. A laser range/range rate docking system emulator was developed and is being incorporated into the docking controller system to allow simulations to develop laser control system parameters.

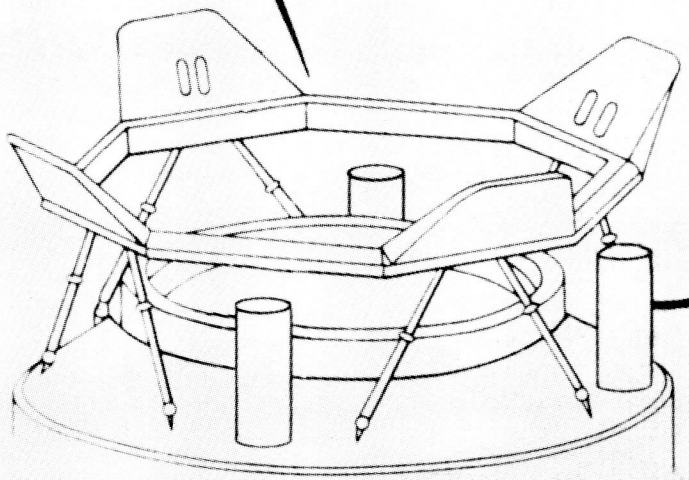
Design and fabrication of a preloadable capture/structural latch has been completed and test preparations are proceeding. An analysis of actuator geometry effects on docking ring movement has been conducted to select an "optimum" system geometry. A preliminary stress analysis of the docking ring was accomplished and ring redesign initiated. Composite materials candidate components have been identified and design of one element was initiated.

TECHNICAL CONTACT: Jerry E. McCullough, JSC (713) 483-2561

CONSTRUCTION/DOCKING TECHNOLOGY

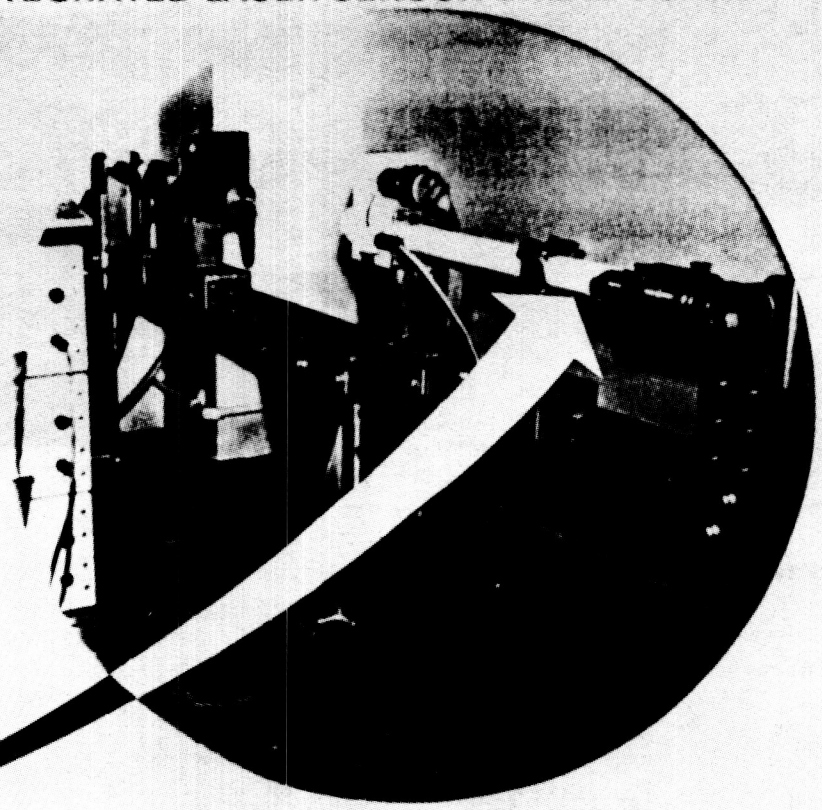


ELECTROMECHANICAL
ACTUATOR/ATTENUATOR
DEVELOPMENT TEST



DOCKING/BERTHING MECHANISM

INTEGRATED LASER SENSOR BREAD BOARD



ACCOMPLISHMENTS

- DOCKING AND BERTHING ANALYTICAL PROGRAM
- INTEGRATION OF CONTROLLER AND SENSORS INTO EMAA DESIGN
- MECHANICAL COMPONENT ANALYSIS, DESIGN, AND DEVELOPMENT
- COMPOSITE MATERIAL USAGE IDENTIFICATION
- APPLICATION OF TECHNOLOGY TO SPACE STATION

AOTV GN&C Research

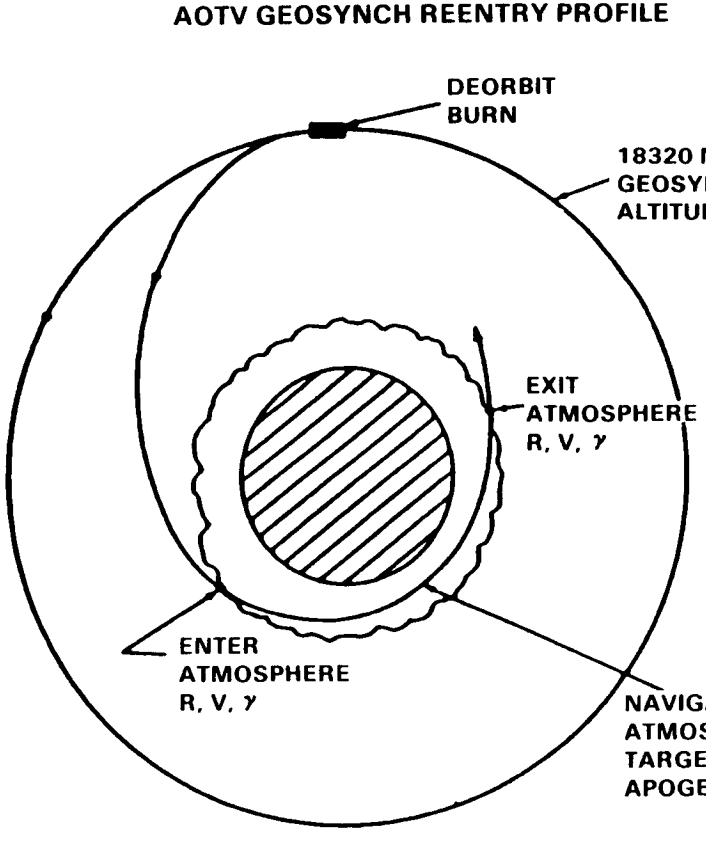
The aero-assisted orbital transfer vehicle (AOTV), which will be used to ferry between the Space Station in low earth orbit and spacecraft in geosynchronous orbit, will use the drag generated by flying through the upper atmosphere as braking for slowing from geosynchronous orbital speeds to low earth orbital speeds. This will reduce the delta-V required for the circularization burn at low earth orbit by the amount of velocity lost by flying through the atmosphere. Since the fuel required for the circularization burn will not have to be carried from low earth orbit to geosynchronous altitudes and back, this technique gives a significant weight saving over the all-thrusting orbital transfer vehicle.

The Spacecraft Control Branch of the LaRC Guidance and Control Division (GCD) has recently been given the task of spearheading Guidance Navigation & Control (GN&C) research for future space transportation systems through the chairmanship of the AOTV GN&C Steering Committee. This committee recently put together a Technology Development Plan for NASA AOTV GN&C research which includes the areas of Atmospheric Modeling/Aerodynamics, GN&C Technology Integration, Modeling and Simulation, GN&C Algorithms, Avionics Systems/Architecture, and Flight Experiments (see opposite figure).

The Spacecraft Control Branch will have direct responsibility for work in the areas of GN&C Algorithm Development and Modeling and Simulation. Currently, in-house simulation capability for use in examining existing trajectory algorithms is being developed. This capability will also be used in developing and testing new algorithms for the atmospheric portion of the AOTV flight. New techniques for trajectory optimization using singular perturbation methods to reduce the computational burden are being investigated.

TECHNICAL CONTACT: Dr. Douglas B. Price, LaRC (804) 865-4681

AOTV GN&C RESEARCH



- AOTV GN&C Steering Committee
- In–house research
  - Algorithm Development
    - Singular Perturbation techniques
  - Modeling and Simulation
    - Develop large and small scale simulations

Guidance, Navigation, and Control for Future Aeromaneuvering Vehicles

A number of future space transportation vehicles, strategic vehicles, and planetary spacecraft will make use of aerodynamic forces to enable them or enhance their ability to meet mission objectives. Examples of such vehicles are the Aeroassisted Orbital Transfer Vehicle (AOTV), the Shuttle II, and Earth-Moon Transportation Vehicle, an Entry Research Vehicle (ERV), a Transatmospheric Vehicle (TAV), and spacecraft for the following missions: Mars Sample Return, Manned Mars, and Comet Nucleus Sample Return.

These vehicles have requirements that include performing energy depleting atmospheric skip trajectories, synergetic plane changes, and landing precisely with large downrange and crossrange capability. These are new and challenging requirements for reentry guidance, navigation, and control (GN&C). The requirements must be met despite considerable uncertainty in the flight environment, most notably the atmospheric density. Furthermore, the GN&C system should be flexible and require minimal ground support, and should command and control flight that not only meets the mission objectives, but does so in an efficient manner.

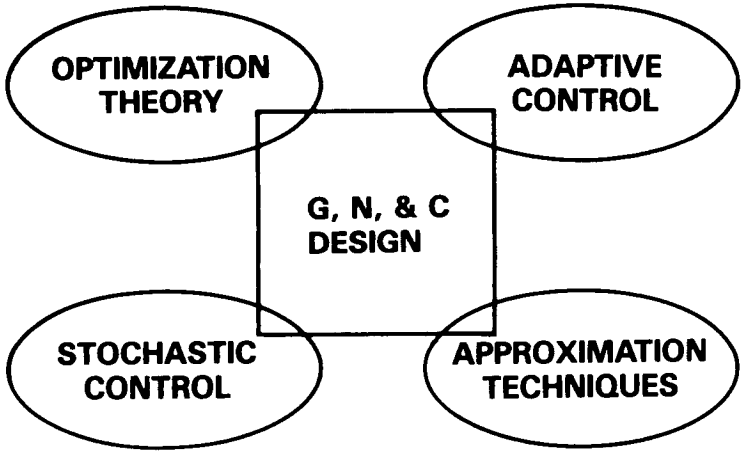
A technology advancement program to develop and demonstrate efficient and reliable GN&C concepts for future aeromaneuvering vehicles is ongoing at JPL. In order to meet this technical challenge, the program is conducted by a broad-based team of in-house and university researchers, whose combined expertise covers the areas of orbital mechanics, atmospheric flight mechanics, attitude dynamics, optimization, estimation, and stochastic control.

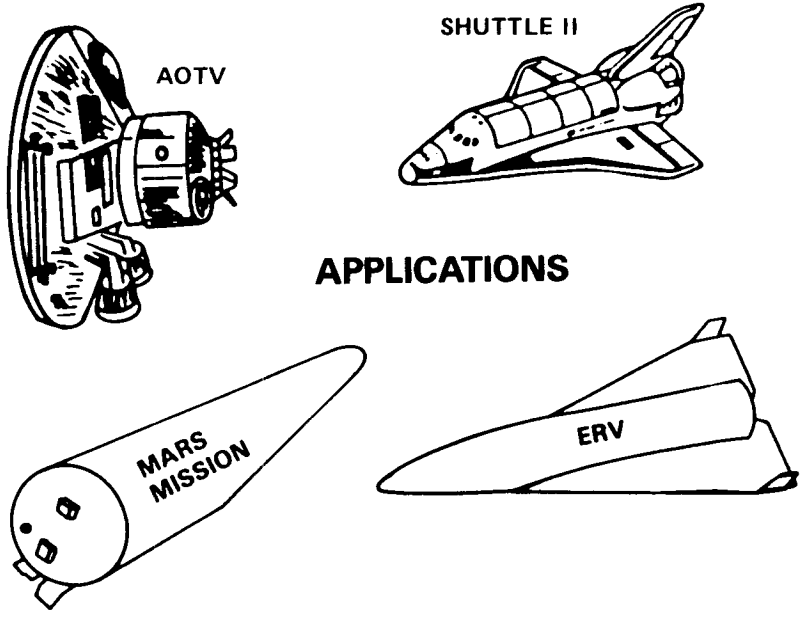
Previously, optimal trajectories and controls for a wide range of aeromaneuvering applications were determined. These results provided a basis for the deveopment of practical guidance laws for onboard implementation, which was the focus of the FY 85 work and will continue in FY 86 and FY 87. A particular accomplishment in FY 85 was the development of an explicit guidance law for controlling the longitudinal motion of a vehicle during a skip trajectory (see opposite figure). The basis of the guidance law is an approximate analytical solution to the equations of motion, obtained by a singular perturbation method.

The anticipated benefit of this program is a set of efficient, integrated solutions to the classic GN&C problems posed by future aeromaneuvering vehicles--solutions that maximize performance, capability, and reliability and minimize operational costs and complexities.

TECHNICAL CONTACT: Ferando Tolivar, JPL (818) 354-6215
Ken Mease, JPL (818) 354-7577

GUIDANCE, NAVIGATION, AND CONTROL FOR FUTURE AEROMANEUVERING VEHICLES





PAYOFFS

- INCREASED CAPABILITY
- ADAPTIVE TO OFF-NOMINAL CONDITIONS
- FUEL OPTIMAL FLIGHT
- INCREASED AUTONOMY AND MISSION FLEXIBILITY

ACCOMPLISHMENTS

- OPTIMAL TRAJECTORIES AND CONTROLS
- EXPLICIT GUIDANCE LAW FOR ENERGY DEPLETION

Fiber Optic Rotation Sensor (FORS)

The objective of this program is to develop a 10 year lifetime, low cost, higher reliability, high performance, navigation-grade optical gyroscope using semiconductor lasers, fiber optic waveguides, and integrated optical waveguide circuits for operation at 1.3 micron wavelength.

A contract was placed with AT&T Bell Labs in May, 1984, for the integrated optics. All of the 1.3 micron components (switches, polarizing beam splitters, phase modulators) and the fiber attachment process have been previously demonstrated at AT&T. The present contract will demonstrate component performance for a single common processing schedule.

An advanced optical circuit, recently conceived, will perform all key signal processing functions. This design features a closed loop phase control which provides for operation over a very wide range of rotation rates. The output signal is an incremental position angle and "beats" like a ring laser gyro (RLG). There is no scale factor non-linearity at null, which occurs with the RLG. The optical circuit fits on a 5 cm long chip.

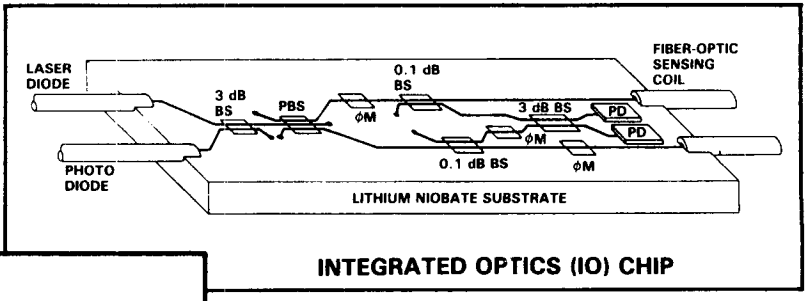
An "all-fiber" 1.3 micron fiber optic rotation sensor test bed utilizing 4.2 km single mode fiber with synchronous detection has been constructed and is now operational in the FORS laboratory (see opposite figure). State of the art performance results have been recently accomplished with rotation rate noise amplitude of 0.135 degree/hr and a corresponding short term random drift coefficient of 0.007 degree/hr. This "all-fiber" rotation sensor is to provide a test bed for component evaluation at 1.3 micron.

TECHNICAL CONTACT: Ferando Tolivar, JPL (818) 354-6215
Ramon P. DePaula, JPL (818) 354-4455

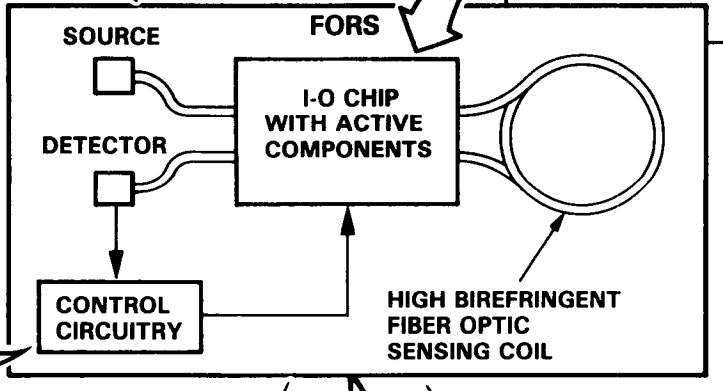
FIBER OPTIC ROTATION SENSOR (FORS)

PAYOFFS

- LONG LIFE (ALL SOLID STATE)
- HIGHER RELIABILITY
- HIGHER PERFORMANCE



INTEGRATED OPTICS (IO) CHIP



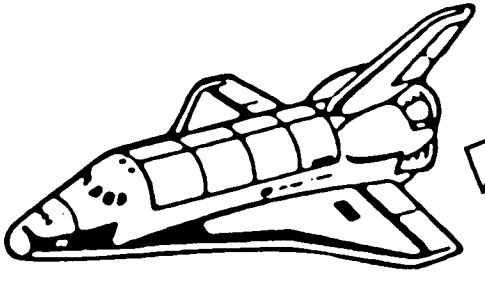
OUTPUT

SPACECRAFT ANGULAR POSITION AND RATE

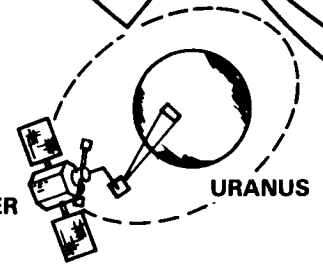
ACCOMPLISHMENT

- 1.3 μ m "ALL FIBER" ROTATION SENSOR TEST BED OPERATIONAL
- STATE OF THE ART DEMO OF 0.15°/HR DRIFT RATE

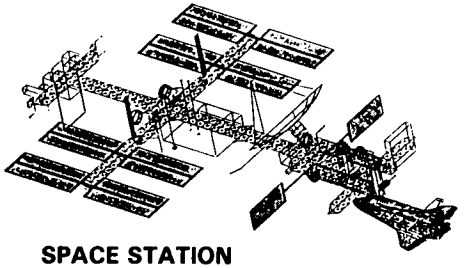
APPLICATIONS



SPACE SHUTTLE



MARINER MK II



SPACE STATION

Advanced Autopilot for Spacecraft (AAPS)

The program objective is the design, development and flight demonstration of the operational benefits of an advanced autopilot for control of on-orbit spacecraft. Currently, autopilots provide inefficient control solutions due to axis-by-axis control laws, separate solutions to rotation and translation control requests and precalculated jet selection tables. This results in excessive fuel consumption and increased thruster operation, creating long term maintenance problems. The Advanced Autopilot provided an efficient, integrated solution to these problems through a six-dimensional phase space control law which provides a combined solution to rotational and translational commands and calculates fuel-optimal jet selections and firing durations.

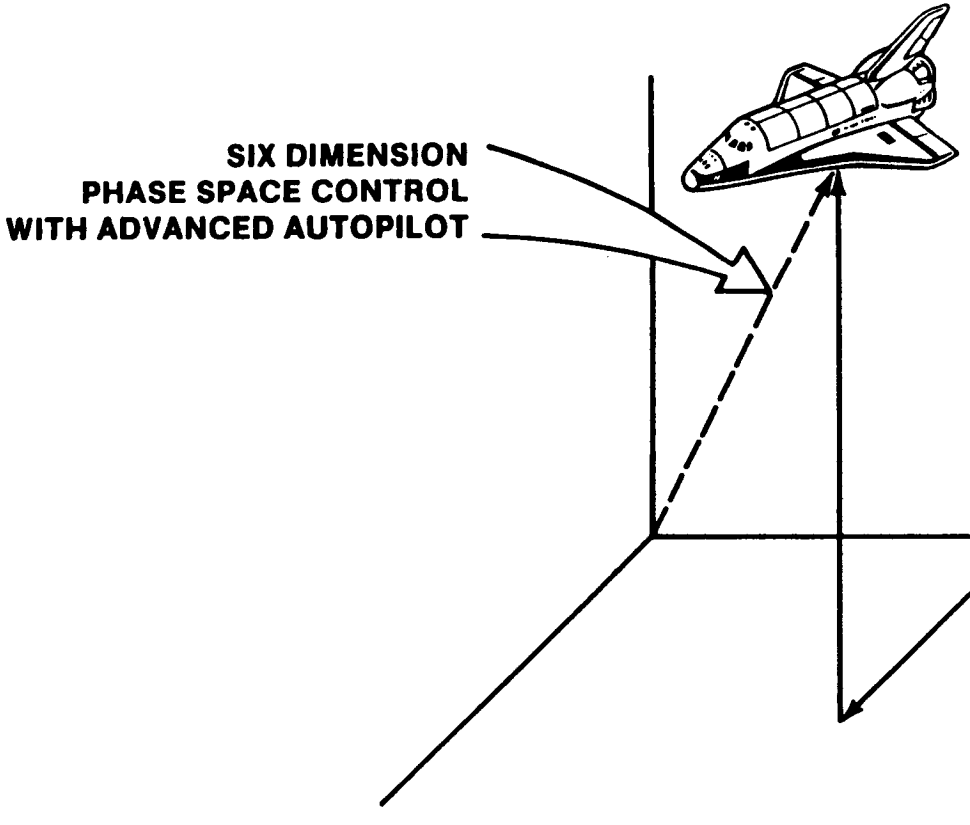
The Advanced Autopilot has been developed and incorporated into the Space Shuttle on-orbit software (see opposite figure). Its first flight test took place on STS 51-G during June 1985. All test objectives were successfully met. Several Shuttle firsts were achieved, including first combined use of primary and vernier jets, first closed loop automatic station keeping with a target position programmed in its onboard computer, and first onboard adaptation to change in mass properties. Its second flight test in November on STS 61-B was also successful, with the autopilot automatically accomplishing station keeping and rendezvous with a deployable corner cube reflector target and the shuttle S-band radar sensor system. The expected benefits of this project are to provide an autopilot which is more fuel-efficient, maximally tolerant to reaction jet failures and easily adaptable for use on other spacecraft.

TECHNICAL CONTACT: Ed Chevers, JSC (713) 483-2851

STS GN&C System Technology
Advanced Autopilot

ATTRIBUTES

- OPTIMAL FUEL CONSUMPTION
- ADAPTS TO MASS PROPERTY CHANGES
- RECONFIGURES FOR FAILED JETS



ACHIEVEMENTS

- AUTOPILOT CODED AND VERIFIED
- INCLUDED IN ORBITER OI-6 FLIGHT SOFTWARE BUILD
- SUCCESSFULLY FLOWN ON FLIGHTS 51-G, AND 61-B

STS Guidance and Control

Operational experience in orbital deployment and manipulation of payloads of various sizes using the Orbiter indicates the need to reduce the sensitivity of the control system to changes in the combined Orbiter/payload mass/inertia properties and center-of-gravity location. Present control system technology, as reflected in the Orbiter design, is limited in the range of these properties that can be accommodated without costly and time-consuming software changes. Also, the requirement to ensure adequate stability and efficient performance with vastly different payload mass/inertia properties results in a relatively long-term, sustaining engineering force during the operational phase. This requirement thus assures payload/flight control system (FCS) compatibility on a mission-by-mission basis. Advanced vehicles such as Space Station will entail much larger changes in plant characteristics during build-up, with larger uncertainties than ever before.

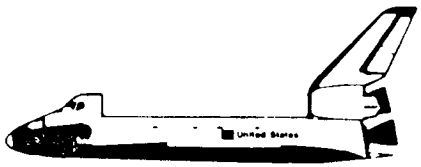
JSC has initiated a technology advancement program to develop the requirements and perform a typical FCS design that is inherently adaptive to large variations and uncertainties in mass/inertia properties, control effector configuration, and external disturbances such as aero and gravity gradient torques (see opposite figure). The approach is as follows: to investigate methodologies to reduce the potential for dynamic interaction within an Orbiter-type digital autopilot; to determine the expected variations and uncertainties of the driving parameters for future vehicles; to deploy new methods for providing traceability of design-driving requirements through all levels of software and design implementation documentation; and finally, to apply the resulting design concept improvements to a control system design problem for a typical large, flexible spacecraft. This requires three specific study areas: (1) definition of the limits of the present control envelope, (2) development of a new method for software requirements documentation and control, and (3) development of requirements and software models for a large vehicle control system that is autonomously adaptive to all rigid body and external disturbance parameters.

A hierarchy of over 100 software functions defined by the JSC Space Station Attitude Control and Stabilization Test Bed including descriptions, originating source, and input/output data were loaded into a VAX 11/780 computer to demonstrate how automated tools can be used to store and manage software requirements and to perform analyses which check the completeness and consistency of those requirements. Also, the feasibility of using an advanced Program Design Language to expand a requirements data base into a complete software design was demonstrated. This demonstration was a significant step in bridging between computer-aided requirements definition tools and computer-aided tools used for computer program design.

TECHNICAL CONTACT: Paul C. Kramer, JSC (713) 483-3254

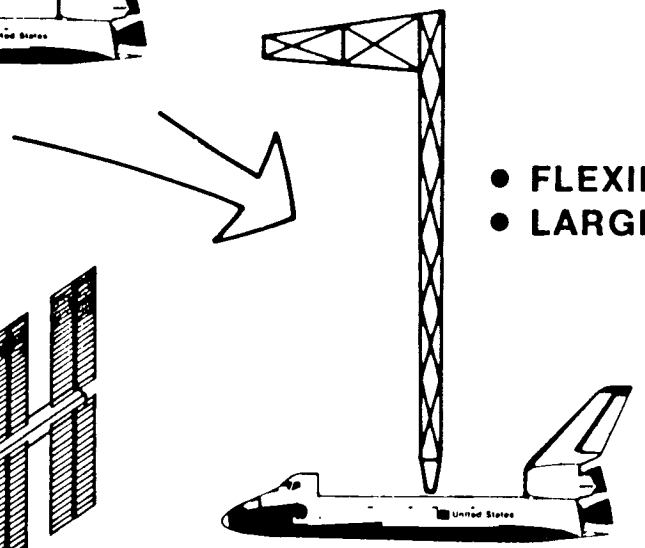
STS Guidance and Control

- RIGID BODY
- SMALL CG TRAVEL

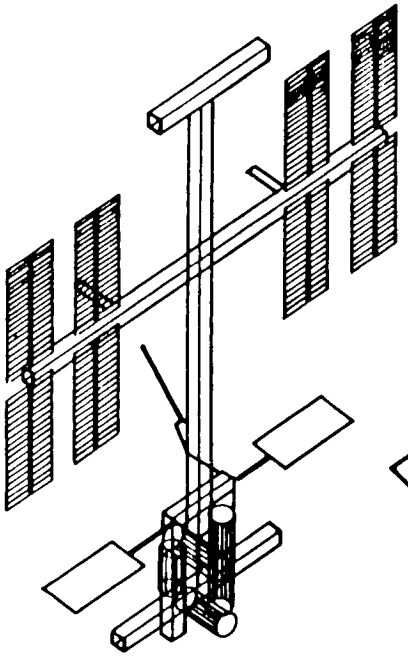


ACCOMPLISHMENTS

- CONFIGURATIONS DEFINED
- THREE CONTROL SYSTEMS STUDIED



- FLEXIBLE APPENDAGES
- LARGER CG TRAVEL



PAYOFF

- SINGLE CONTROL SYSTEM:
  - STABILIZES LARGE FLEX BODY
  - BUILDS UP STATION
- REDUCED SOFTWARE COSTS

Data Systems

The Data Systems Program consists of research and technology devoted to controlling, processing, storing, manipulating, and analyzing space-derived data. The objectives of the program are to provide the technology advancements needed to enable affordable utilization of space-derived data, to increase substantially the capability of on-board processing for future missions, and to provide computational systems anticipated for missions such as the evolutionary Space Station and Earth Observing System.

The Data Systems Program supports fundamental research in laser diodes, supports work to select and provide the appropriate on-board processor technology for future NASA missions, and also supports the development of two processors with special architectures. The ongoing support for solid state laser research leads directly to the development of a 9 laser diode array which is used in the Optical Disk Buffer. The laser fundamental research is also focusing some effort applicable to Space Station data handling applications. These devices are being developed to handle both the 300 Mbit/sec basic data rate and the much higher rates needed to support networking and computer internal communications. Complementary research is being supported to characterize the fundamental performance and properties of various alternative networking.

NASA missions require processors that will work very reliably in a space environment. Computer systems for missions in polar orbit and some planetary missions must operate reliably in high radiation environments. These requirements match closely, but not exactly, with many products being produced for DOD applications. NASA technical expertise is being applied in cooperative arrangements with DOD. Products from the DOD VHSIC program, and other DOD development, are being assembled into processors for test and evaluation.

The Advanced Digital SAR Processor, which has special architecture and algorithms to process SAR data, is within a year of completion. The completed unit will have a compute rate of 6000 Megaflops per second. The Massively Parallel Processor (MPP) is being used for ground processing of space image data, SAR data, and spectral analysis. The MPP utilizes 16,384 processors. The research in process has verified the expected tremendous computational power of the MPP for the target applications. Researchers outside of NASA in several universities, research centers, and industry have been provided access to the MPP to gain an understanding of the capabilities of the MPP when applied to a broad range of computational problems.

The Data Systems program also includes support for the evaluation of products from the DOD ADA Program. This includes a test bed activity to several vendors' versions of the language and associated support products. A major accomplishment from this work is that the ADA language was selected as the language of choice for Space Station.

PROGRAM MANAGER: Richard Grumm
NASA/OAST/RC
Washington, DC 20546
(202) 453-2753

Advanced Distributed System Networks

The focus of this program is on the characterization of high-speed Local Area Networks (LANs) for spaceborne use, and particularly to emphasize capabilities which apply to the data system requirements of the Space Station (see opposite figure). The primary method has been to use discrete event simulation to understand concepts in detail. This is being augmented and validated through analysis and emulation on commercial workstations and LANs. Detailed modeling of workloads (or scenarios of required services) is an important element in the studies. The network simulations may be used agency-wide for various studies.

The benefits of these studies are derived from a deeper understanding of the data flow and response requirements in distributed processing architectures. They help to fill a gap in current network research by providing better analysis tools which aid in NASA/user community and inter-NASA communication. They also enable early, cost-effective evaluation of new data system designs, such as those which will be proposed for the Space Station. Reliability and performance characteristics of both hardware and software elements can be combined into a system evaluation.

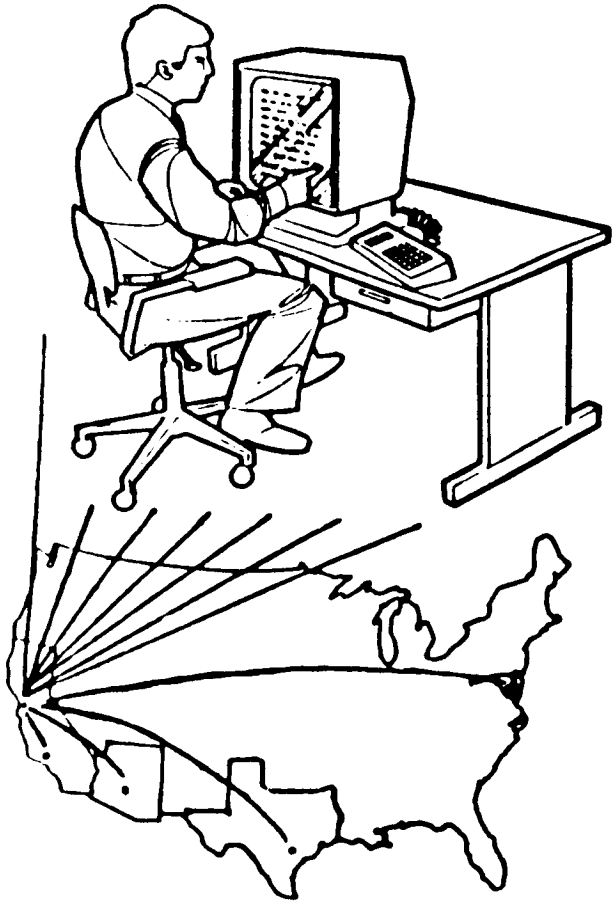
The initial model under the LAN extensible simulator (LANES I) has been released and has helped in the first comparative studies of the star-coupled Fiber Optic Data System under development by GSFC. Documentation includes a requirements specification and a user's manual. The computer simulations have been remotely activated and monitored at several sites around the U.S. through the use of the Telenet Wide Area Network.

The second model, LANES II, is targeted for release by the end of FY 85 and simulates the "Fiber-Optic Digital Data Interface (FDDI)" under an ANSI draft specification for a high-speed fiber-optic token ring. The requirements specification is complete and the user's manual is in review.

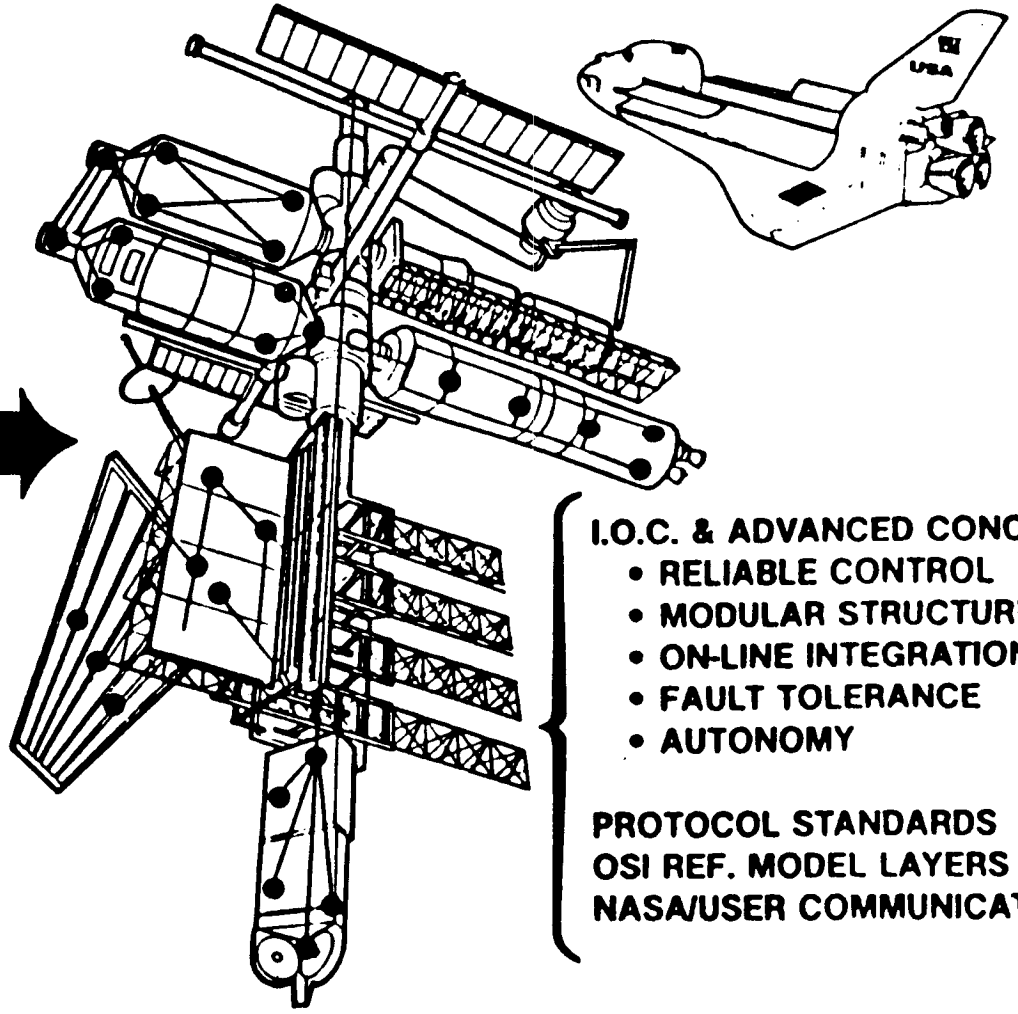
TECHNICAL CONTACT: Terry L. Grant, ARC (415) 694-6526.

ADVANCED DISTRIBUTED SYSTEM NETWORKS

SIMULATION & ANALYSIS



SPACE STATION DISTRIBUTED SYSTEM ARCHITECTURE



I.O.C. & ADVANCED CONCEPT
- RELIABLE CONTROL
- MODULAR STRUCTURE
- ON-LINE INTEGRATION
- FAULT TOLERANCE
- AUTONOMY

PROTOCOL STANDARDS
OSI REF. MODEL LAYERS
NASA/USER COMMUNICATION

On-Board High Speed Adaptive Processor

The objective of this program is to advance the state-of-the-art in on-board sensor image data processing and storage through the use of advanced GaAs integrated circuit technology. The key requirements of such hardware include very high throughput (potential 1 to 3 Gbps applications), radiation tolerance, programmability and low power. The solution lies in an Adaptive Programmable Processor (APP) chip set with programmable emulating capability, wide bandwidth I/O, and memory fast access. This chip set is designed around the 8 bit Slice General Processor (SGP) using GaAs technology. The SGP device is an 8 bit execution unit capable of performing both arithmetic and logical operation on data that can be connected to form a 16, 24, 32 bit or wider operation system. The 8 bit SGP chip architecture is modeled after the RCA GPU Family (CMOS/SOS) which has demonstrated emulation of the MIL-STD-1705A instruction set on the Navy Standard 16 Bit Micro-Computer (AN/UYK 20). The initial chip set will consist of four device types:

(1) 8 Bit Slice General Processor, NASA, design completed

(2) General Purpose ROM, BMD, fabricated and tested

(3) IK GATE ARRAY, IR&D, DARPA, fabricated and tested

(4) 4K Bit RAM, DARPA, fabricated and tested

The program goal is to implement the DPCM image data compression algorithm (supplied by NASA) by augmenting the 8 bit SGP with a gate array whch provides support logic for the SGP (I/O and control sequencer for the compression algorithm). These two chips will have the capability of performing the DPCM image compression algorithm in 15 nanoseconds when supplied with a 200 Mz clock.

A future addition to the chip set will include a control sequencer with an internal ROM chip which will contain either the MIL-STD-1750 or National 32032 microprocessor (NMOS) instruction set.

TECHNICAL CONTACT: Warner Miller, GSFC (301) 344-8183

ON-BOARD HIGH SPEED ADAPTABLE PROCESSOR

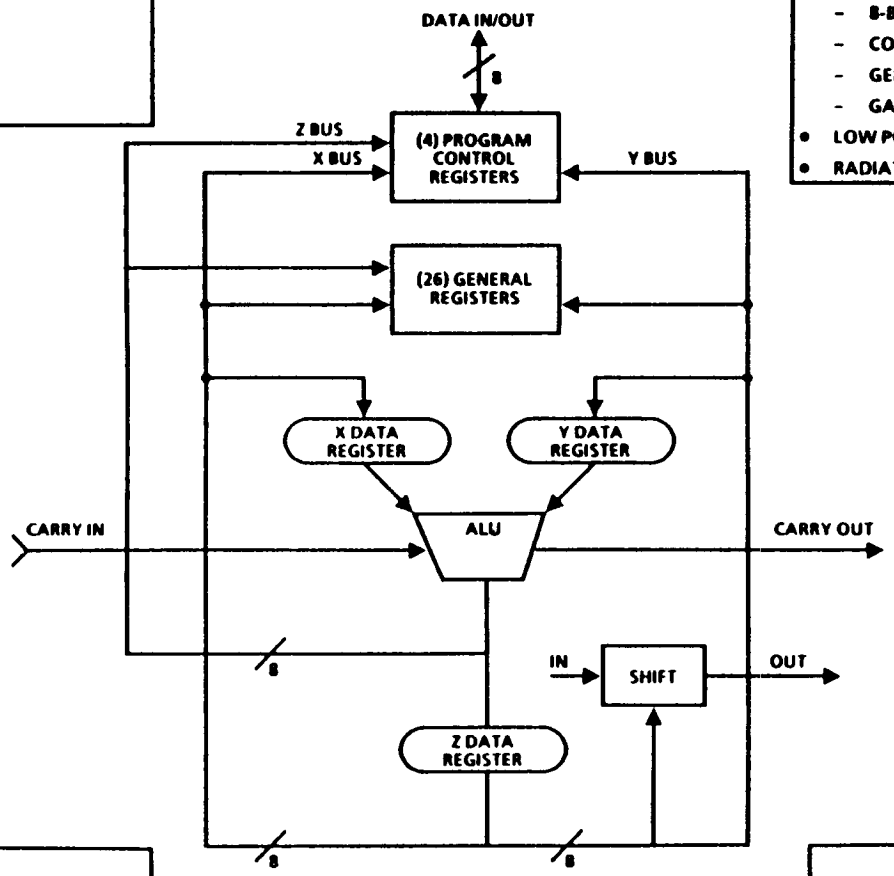
PERFORMANCE GOALS

CLOCK RATE: 200 MILLION CLOCKS/SECOND

ADD TIME: 5 NSECS

8 X 8 MULTIPLY TIME: 25 NSECS

THROUGHPUT WITH NON-UNIFORM QUANTIZER: 150 MIPS



8-BIT SLICE GENERAL PROCESSOR FUNCTIONAL BLOCK DIAGRAM

PROCESSOR CHARACTERISTICS

- ADAPTABLE PROGRAMMABLE CHIP SET:
  - 8-BIT SLICE GENERAL PROCESSOR UNIT
  - CONTROL SEQUENCER AND RAM
  - GENERAL PURPOSE ROM
  - GATE ARRAYS FOR INPUT/OUTPUT
- LOW POWER .5-2 MWATTS/GATE
- RADIATION HARD 50 MRADS TOTAL DOSE

STATUS

- DEVELOPED CHIP SET ARCHITECTURE
- DESIGN IN PROCESS FOR 8-BIT SLICE AND GATE ARRAY

CURRENT WORK

- DEVELOP AND DEMONSTRATE NON-UNIFORM QUANTIZER
- AUGMENT PROGRAM TO DEVELOP 1750 ARCHITECTURE

Fiber Optic Data System

The fiber optic data system, now termed Star*Bus, is an advanced high rate (100 mb/s), packet switched data system keyed to spacecraft applications. The brassboard system fabricated by Sperry Flight Systems of Phoenix, Arizona is being demonstrated in GSFC's Flight Data Systems Branch test facility.

The primary emphasis was to develop the first two layers of the International Standards Organization (ISO) recommended data management architecture. Layer 1 uses a 32 x 32 passive optic star coupler in a redundant configuration for high reliability and simplicity of function with dual optical transmitters and receivers on each bus interface unit. Other simple, reliable optical components used are LEDs and PIN photodiodes. These components should prove to be long-lived, low power, reliable elements.

Layer 2 of the architecture employs a bus access protocol that is self-starting, autonomous, and self-adjusting to bus-loading. It exploits the performance characteristics of Carrier Sensed Multiple Access (CSMA) for low traffic intensity and the good performance of a "time slot" protocol for high traffic intensity. One important feature of the topology is the capability to disconnect nodes on the network with no effect on the operation of the other nodes. Another important characteristic of the system is the predicted greater than 80% bus utilization with mean transfer delays on the order of milliseconds.

The demonstration system has been transferred to the Space Station Focused Technology Program for use in the Data Management System Test Bed. Future development involves implementing layers 3 and 4 of the ISO architecture and reducing the power dissipation by means of VLSI technology using both gallium arsenide (GaAs) and high speed CMOS in the bus interface units.

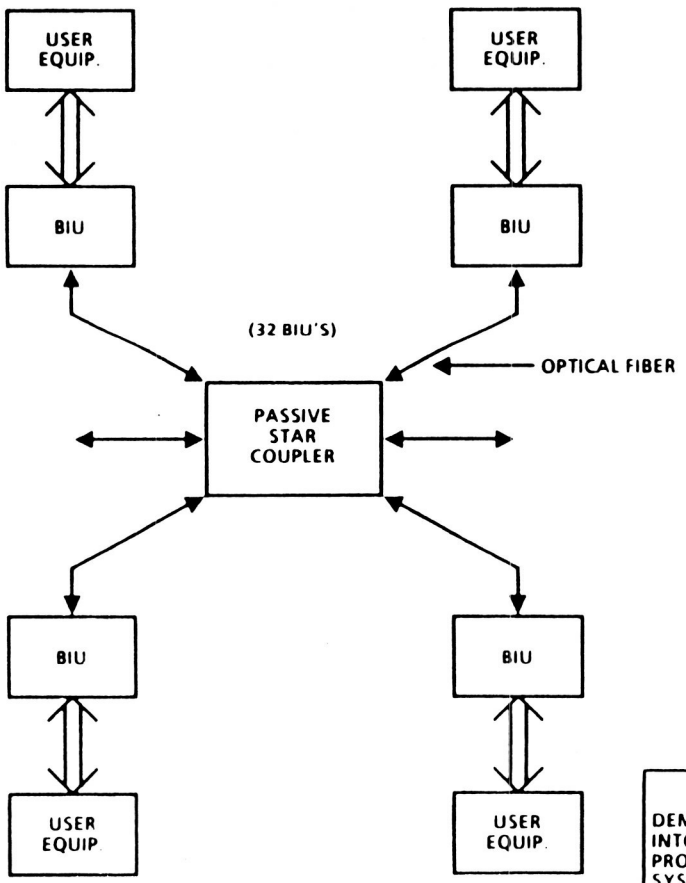
TECHNICAL CONTACT: John Rende, GSFC (301) 344-5529

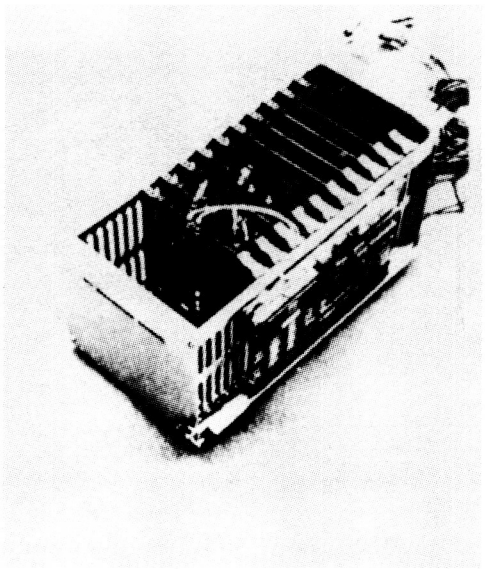
FIBER OPTIC DATA SYSTEM

FODS CHARACTERISITICS

- 100 MBPS FIBER OPTICS
- PASSIVE STAR COUPLER
- DISTRIBUTED NETWORK CONTROL
- MEDIA ACCESS DYNAMICALLY ADAPTABLE TO BUS LOADING
- PACKET DATA TRANSFER
- REDUNDANT STAR COUPLERS, TRANSMITTER/RECEIVERS IN EACH BUS INTERFACE UNIT
- RS-232 AND HIGH SPEED 32 MB/SEC INTERFACES

FIBER OPTIC DATA BUS SYSTEM BLOCK DIAGRAM





STATUS

DEVELOPED AND DEMONSTRATED 8-BUS INTERFACE UNIT FIBER OPTIC SYSTEM

CURRENT WORK

DEMONSTRATION SYSTEM TO BE INCORPORATED INTO SPACE STATION FOCUSED TECHNOLOGY PROGRAM FOR USE IN THE DATA MANAGEMENT SYSTEM TEST BED

Fiber Optics Transceiver

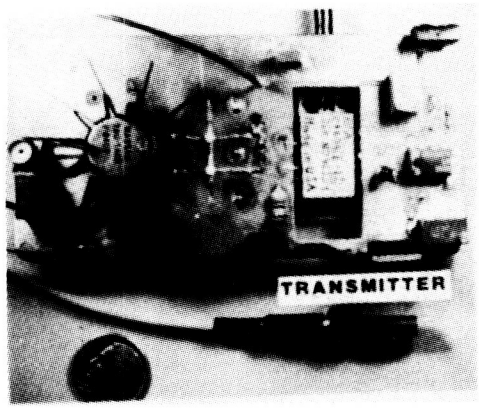
Research and technology in this area has evolved from the development of laser and detector components to the design of preamplifier and laser modules for integration into fiber optics transceivers. This technology enables communications between the optical domain of fiber optics networks to the electronic domain of digital data processors.

In-house laboratory development of a 500 MBit fiber optics transceiver has been completed. The transmitter and receiver are pictured in the left side of the figure on the opposite page. This pair utilizes preamplifier and laser drive modules to achieve a size reduction of at least 3:1 over commercially available devices. The transceiver has a sensitivity of -35 dBm, a dynamic range of 20 dB, and a bandwidth of 500 MBits. When evaluated in a network, a bit error rate of less than 10^{-10} is achieved.

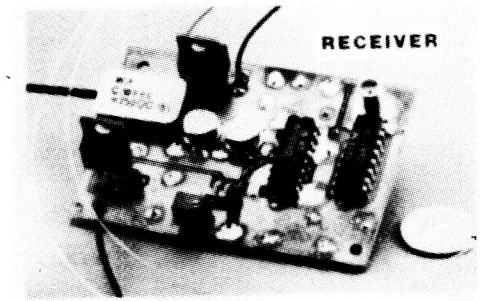
NASA's efforts to advance fiber optics technology and to work toward a common development area with DoD have evolved into a joint program between NASA and the Air Force Rome Air Development Command for the development of a family of multipurpose fiber optics transceivers. Five levels of effort are currently underway, as illustrated in the right of the figure. Current interest for Space Station IOC centers around the 200 MBit transceiver for the core information system. The 1 GBit transceiver could satisfy many video, control and data systems requirements for the growth Space Station. The transceivers indicated will be space-qualified for Space Station, and the entire family of transceivers will be military-qualified.

TECHNICAL CONTACT: Herbert Hendricks, LaRC (804) 865-3777

FIBER OPTICS TRANSCEIVER



IN HOUSE LAB DEMONSTRATION



500 MBIT DEMONSTRATED
PREAMP AND LASER PACKAGE
-35dBm SENSITIVITY
3:1 SIZE REDUCTION

COMMON MODULE

MFOX PROGRAM

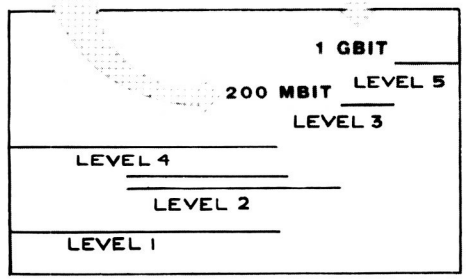
FAMILY OF TRANSCEIVERS

HIGHER LEVEL OF INTEGRATION
MILITARY/SPACE QUALIFIED
3:1 SIZE REDUCTION

A JOINT DOD/NASA PROGRAM

EVOLUTIONARY SPACE STATION

10C SPACE STATION



DATA FREQUENCY, (MHz)

MFOX FAMILY OF TRANSCEIVERS

VHSIC Processor Technology for Advanced Computing

VHSIC embeddable processor technology is being investigated as a candidate to meet anticipated NASA needs in advanced onboard computing applications such as Space Station. NASA studies are focusing on the development and demonstration of computer architecture models and node (or task) assignment methods which take advantage of VHSIC technology in the MIL-STD-1750A Instruction Set format. VHSIC and VHSIC-like 1750A processors are being acquired and evaluated consistent with desired system architecture and sample algorithms. This work should enable NASA to take early advantage of the several 1750A developments sponsored by the DoD, including a spaceborne version by the Air Force.

A major FY85 accomplishment was the performance simulation of a "typical-complexity" algorithm in VHSIC processor architecture. The simulation, made using the OEX Advanced Autopilot Algorithm which provided triplex computations, successfully demonstrated dynamic reconfiguration and fail-safe operation upon occurrence of a failed processor in a multiprocessor system consisting of 4 VHSIC 1750A processors.

Three 1750A brassboards (Fairchild, TI, Westinghouse) are being acquired to be used intially for in-house evaluation. The TI procurement is the first non-DoD acquisition of a VHSIC brassboard. A fourth 1750A processor, under development on a related SBIR Phase II contract, will enable study of fault detection scenarios down to the transistor level. These processors will subsequently be used in studying dynamic node assignment techniques which efficiently provide fail-safe computations in a 1750A asynchronous multiprocessor system. This effort should lead to a hardware demonstration of a 1750A system methodology with Space Station readiness. Work was also begun to obtain architecture design and assessment software, modified to include specific 1750A parameters. Initial work with this software will consider the TI 1750A procesor as the major component in a multiprocessor system. Directed Graph tools were obtained from Westinghouse and supplied to both LaRC and JPL for use in this work.

Computer system model characterization in a VHSIC context will continue. A role will be defined for NASA to participate in, or otherwise take advantage of, two 1750A processor developments which were initiated by the Air Force in FY85. The first, an avionics 1750A with parallel developments by TRW and Westinghouse, should afford VHSIC brassboards in FY87. The second 1750A effort initiated should result in a spaceborne brassboard in FY88 with radiation hardness and functional characteristics similar to the avionics version.

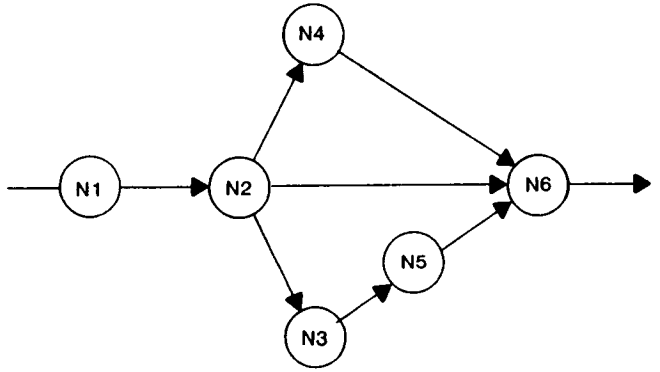
TECHNICAL CONTACTS: Harry F. Benz, LaRC (804) 865-3535
Paul J. Hayes, LaRC (804) 865-3777

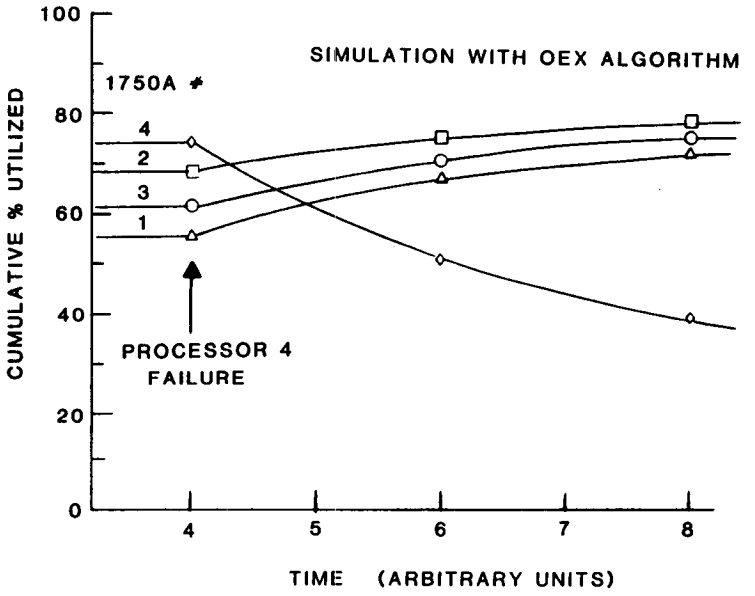
VHSIC PROCESSOR TECHNOLOGY FOR ADVANCED COMPUTING

FAIL-SAFE APPROACHES

1) NODE PREASSIGNMENT WITH DYNAMIC RECONFIGURATION

APPLICATION ALGORITHM

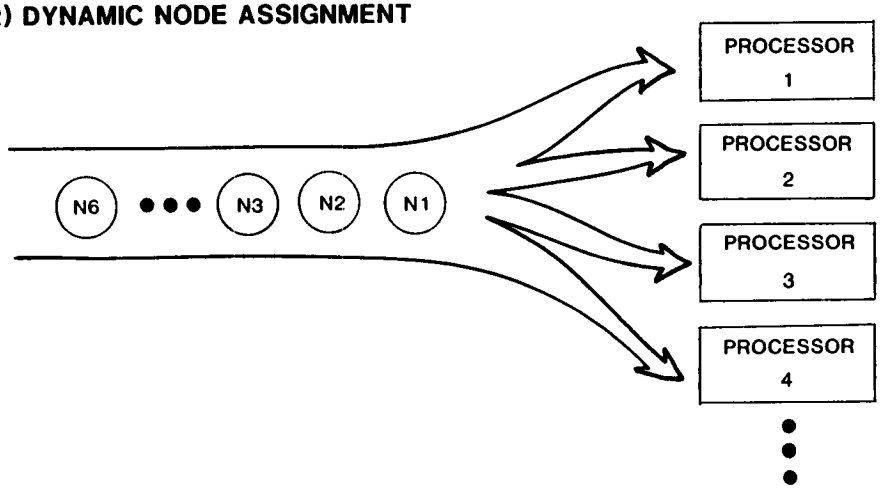




VHSIC MULTIPROCESSOR FEATURES

- o SELF TESTING AND FAULT ISOLATION
- o VERSATILE NODE ASSIGNMENT METHODS
- o TRIPLEX COMPUTATIONS AT NODE LEVEL TO INCREASE FAULT TOLERANCE
- o INCREASED RELIABILITY
- o MODULAR DESIGN FOR EASY MAINTENANCE
- o GRACEFUL DEGRADATION IN UNMANNED APPLICATIONS

2) DYNAMIC NODE ASSIGNMENT



VHSIC Technology Insertion

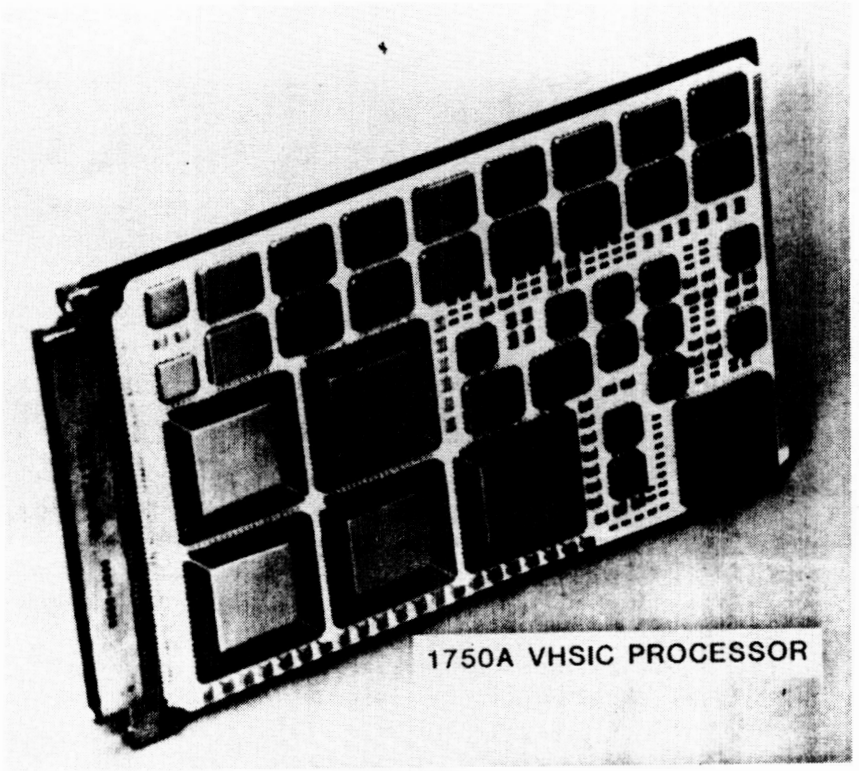
VHSIC technology is being investigated for suitability in meeting anticipated NASA needs in advanced onboard spacecraft applications such as Space Station and Earth Observing System (EOS). VHSIC Phase I technology is expected to provide a 4-fold increase in functional complexity and operating speed as compared to existing 3-micron VLSI chips. VHSIC Phase II technology should result in a further 100-fold increase in throughput. This technology is needed to provide superior processing capability for high throughput onboard applications. The availability of VHSIC CAD/CAM tools, currently under development within the DoD, should lead to economical design and fabrication of advanced and custom chips.

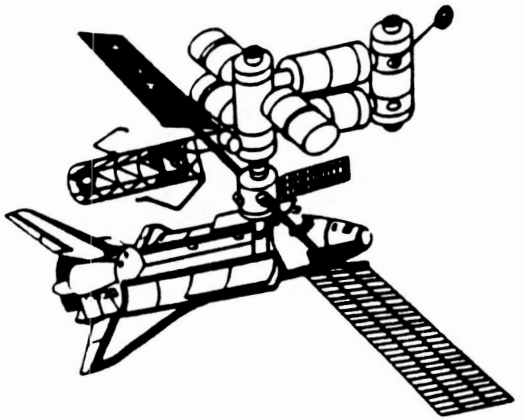
A NASA-sponsored VHSIC workshop with over 140 attendees was held at JSC in November 1984. Phase I devices and concepts were reviewed and several hands-on setups were available to illustrate device versatility and application. A study of the 1990+ NASA instrument requirements was made to identify candidates for implementation with VHSIC devices. Of the 24 planned and opportunity-type missions reviewed, 139 instruments were identified. Thirty-one of these instruments have estimated data rates exceeding 1 Mbps and are believed to be candidates for using VHSIC. A VHSIC committee was formed at LaRC to identify potential applications for early insertion of VHSIC devices and brassboards.

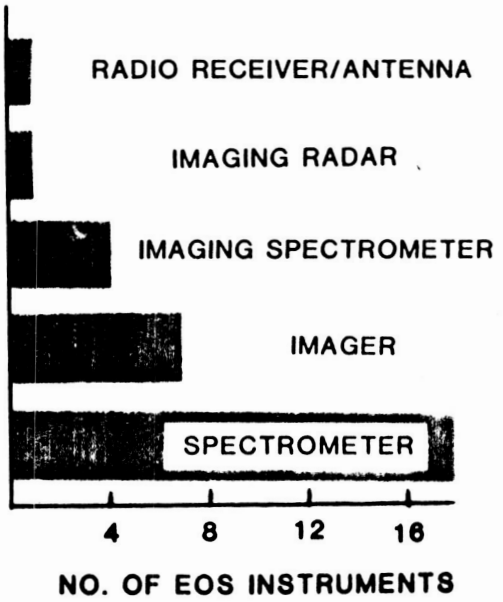
A proposed plan has been developed and is being discussed for a demonstration of advanced technology for Space Station at LaRC. This demonstration would bring together pre-VHSIC or VHSIC processors, fiber optic networking, and high-speed memory in an advanced data system which could show technology readiness for Space Station.

TECHNICAL CONTACTS: Harry F. Benz, LaRC (804) 865-3535
Paul J. Hayes, LarC (804) 865-3777

VHSIC TECHNOLOGY INSERTION







BENEFITS

- o MULTIPLE 1750A PROCESSOR DEVELOMENTS
- o HIGH SPEED
- o FAULT TOLERANT
- o ADA LANGUAGE
- o SIZE,WEIGHT,POWER,RELIABILITY

Advanced Information Processing System (AIPS)

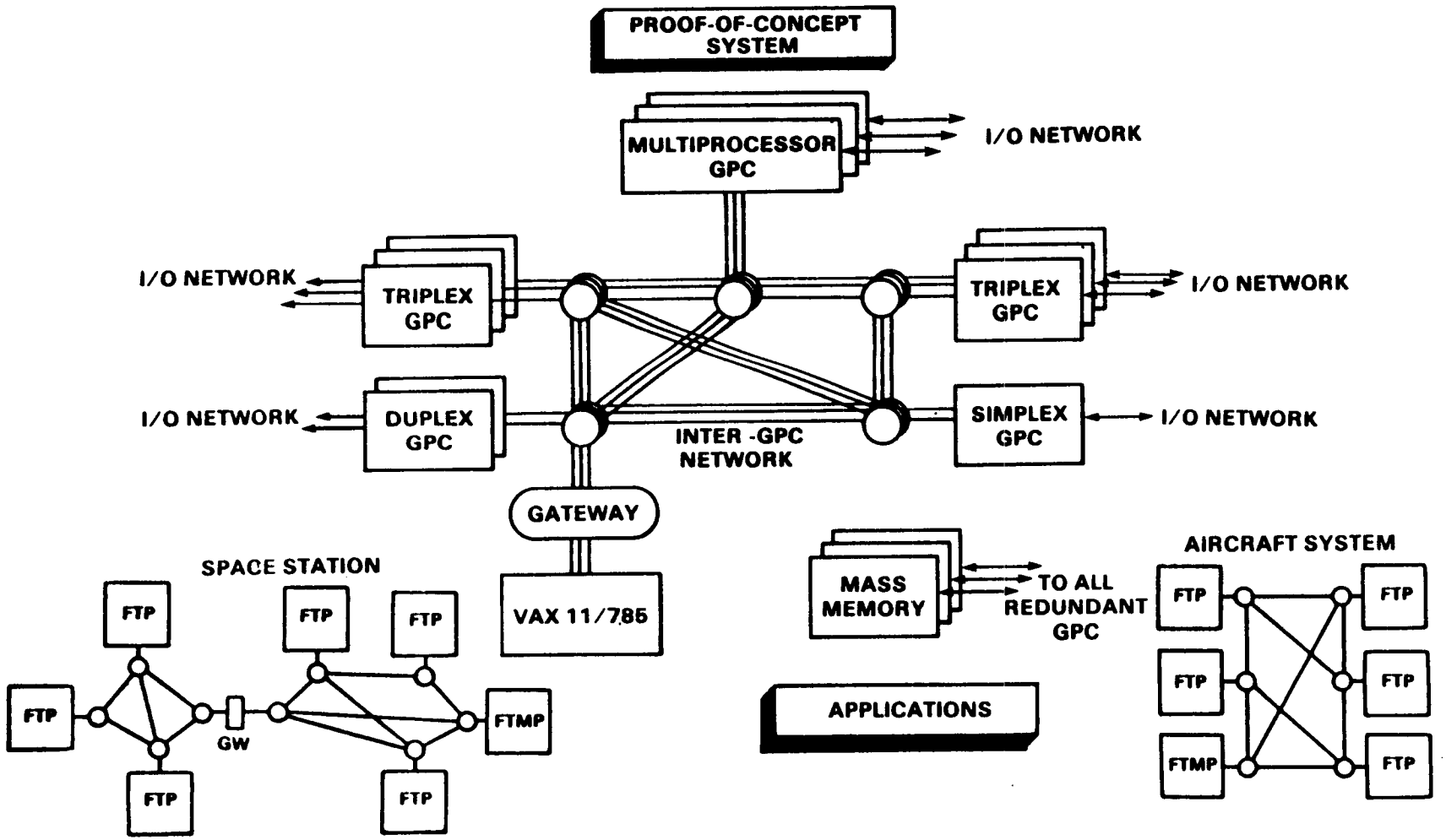
The objective of the AIPS program is to develop and demonstrate a system architecture and the associated design and evaluation methodologies which will effectively serve the need for advanced information processing across a broad spectrum of aerospace missions. Many fault tolerant studies have been conducted in the past, but few have included actual hardware fabrication. Hardware built then was oriented toward a unique set of specifications and very specific subsystems and applications. In contrast, the AIPS program will emphasize core data processing system requirements and their demonstrated adaptability for many different applications.

A system architecture consisting of fault tolerant computer building blocks, computer interconnection networks, and input/output networks was defined previously. The hardware building blocks are augmented by system software which is designed in a service oriented fashion. In addition to providing standard operating system functions such as scheduling and dispatching of tasks and process synchronization, the system software also provides interfunction communication, input/output device communication, fault handling and resource allocation.

Phase II of the AIPS program began in April 1984, and is expected to continue for three years. During Phase II, the proof-of-concept system will be implemented in such a way as to emphasize those system attributes which are based on new or immature technology and which promise significant benefits. Examples of these attributes are the application of fault tolerance to distributed systems, and resource management capabilities to enhance reliability and system flexibility.

TECHNICAL CONTACT: E. S. Chevers, JSC (713) 483-2851

ADVANCED INFORMATION PROCESSING SYSTEM



Spaceflight Tera (10^{12}) Bit Optical Disk Buffer

The objective of the Spaceflight Optical Disk Buffer task is to foster the development and application of erasable optical disk recorder technology to meet NASA spaceflight needs in the 1990s and beyond. This technology has significant advantages over existing magnetic storage systems in terms of storage capacity and input/output data rates. The basic ground and flight optical disk recorder technology is being developed under a multi-agency contract effort, which is in a Phase I - Technology Demonstration program. The objective of this phase is to demonstrate the following capabilities:

- o 8×10^{10} bits (expandable up to 10^{12}) user data capacity
- o 133 Mb/s (expandable up to 1.6 Gb/s) input/output data transfer data rate
- o 10^{-12} corrected bit error rate
- o Modular construction and common recorder-to-controller interface

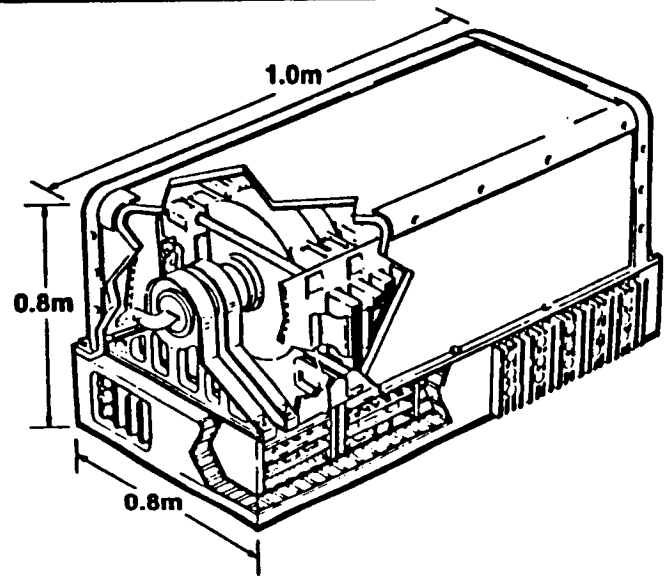
NASA-LaRC's role in this development effort includes: development of controllers which adapt the recorder to NASA mission needs; serving in an advisory role in the development of the recorder/buffer; and leading the multi-center Spaceborne Optical Disk Buffer Subcommittee in the development of recorder requirements. NASA-LaRC will also serve a major role in the evaluation of this technology for future missions and in a major advocacy role in applications to future programs.

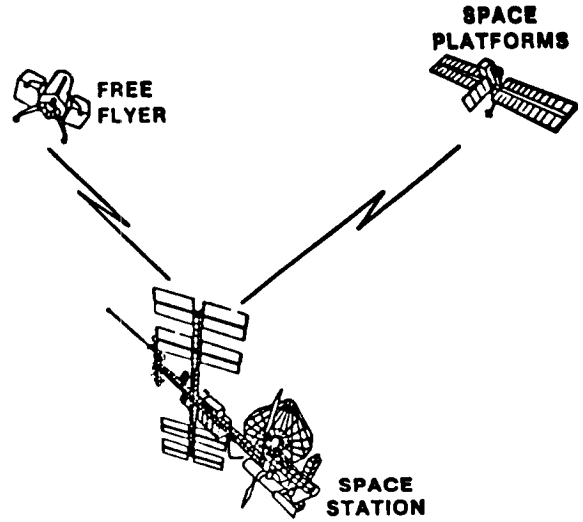
The near-term (FY86) objectives include: further definition of the controller-to-recorder interface; definition of controller/recorder requirements through a focused mission study utilizing the Earth Observing System (EOS) as a model; and initiation of controller concept development.

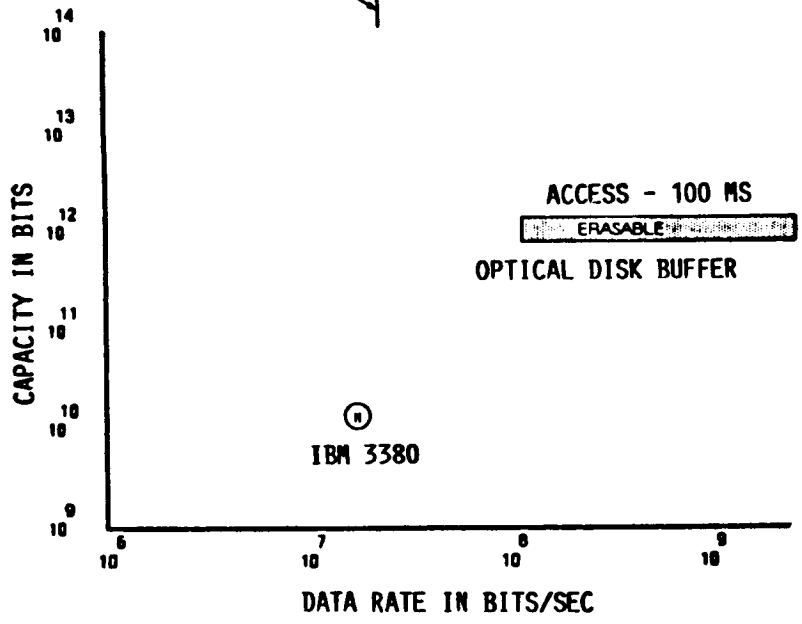
At present, this technology appears to provide the most promise for meeting the high data storage and high data transfer rate requirements of a number of future missions - including EOS.

TECHNICAL CONTACTS: Glenn R. Taylor, LaRC (804) 865-3229
Dr. Thomas Shull, LaRC (804) 865-3541

SPACEFLIGHT TERA (10^{12}) BIT OPTICAL DISK BUFFER







- HIGH DATA TRANSFER RATE CAPACITY (>10^9 BPS)
- LARGE DATA STORAGE CAPACITY (10^{12} BITS)
- FLEXIBLE—CAN SUPPORT MULTIPLE USERS
- RANDOM ACCESS CAPABILITY—SUPPORT ON BOARD PROCESSORS
- MODULAR—EXPANDABLE, RECONFIGURABLE, REPAIRABLE

Advanced Digital SAR Processor (ADSP)

The ADSP is being developed to demonstrate the technology required to meet the SAR data processing requirements of missions in the late 1980's. An engineering model will be built and demonstrated using SIR-B data in FY86.

The algorithm used for both range and azimuth processing is the FFT convolution implemented in a pipeline architecture (as shown in the system diagram). The design will accommodate processing the full swath of SIR-B data at real-time rates. Computational capability is in excess of 6 GigaFLOPS with a dynamic range in excess of 100 dB.

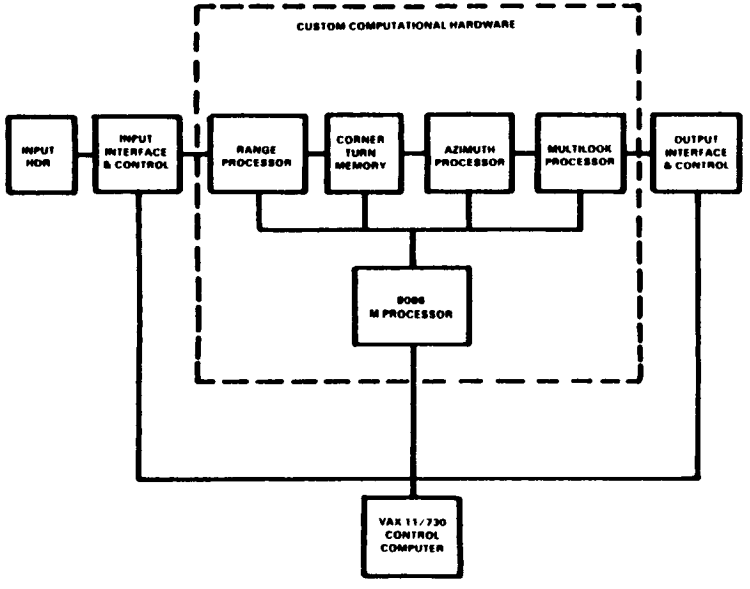
The range correlator hardware (built and tested in FY84) was integrated into the control system and passed all acceptance tests in FY85. The input interface and corner-turn memory (designed, built, and tested in FY85) were also integrated into the system. The portion of the hardware integrated thus far represents 3 GigaFLOPS of compute power and 72 Megabytes of memory. The azimuth processor (including the range migration correction system, the azimuth reference generator, and the azimuth interpolator) were also designed, built, and tested in FY85. The multi-look system will complete design in early FY86 and be integrated during the second quarter.

Demonstrations (with SIR-B data) of single look burst mode and multi-look continuous mode are scheduled for April and July 1986, respectively.

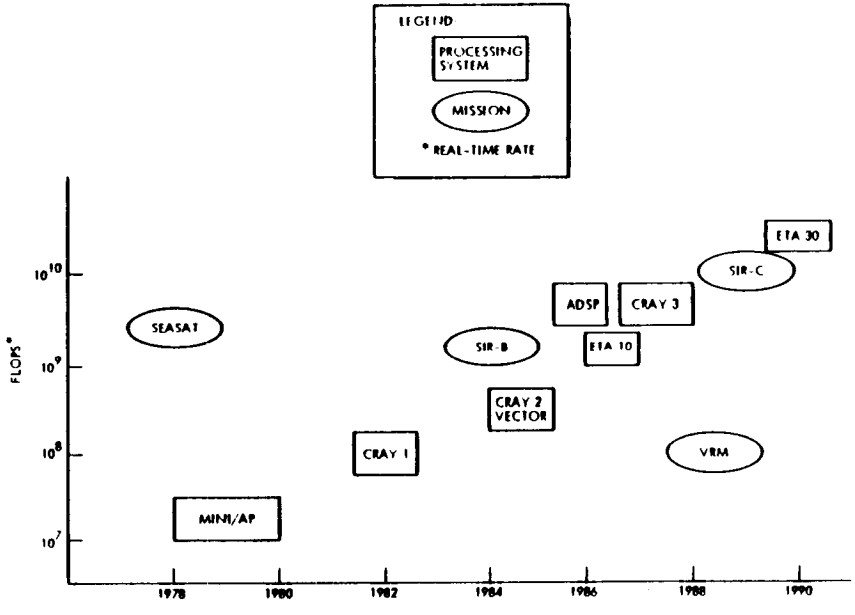
TECHNICAL CONTACT: Thomas Bicknell, JPL (818) 354-2523

ADVANCED DIGITAL SAR PROCESSOR

SYSTEM DIAGRAM



PROCESSING SYSTEMS AND SAR MISSIONS



- MULTI-MISSION SAR PROCESSOR
- 6000 MEGAFLOP COMPUTE RATE (FASTER THAN 10 CRAY COMPUTERS)
- 150 MEGABYTES OF HIGH-SPEED MEMORY

- ONE OF FOUR IN SYSTEM
- 1400 MEGAFLOP COMPUTE RATE
- EIGHT OTHER MODULES REQUIRED TO COMPLETE SYSTEM

MAX - A High Speed General Purpose Multicomputer for Space Applications

MAX is intended for space applications requiring processors with computational rates up to 11 MOPS and with I/O rates up to 300 Mbits/sec. The range includes data handling, guidance and control, and telerobotic applications on earth observing missions such as Space Station and Earth Observing System and on planetary missions such as Mariner Mark II and Mars Rover. It does not include some data compression and processing applications on very high data rate instruments such as those related to High Resolution Imaging Spectrometer (HIRIS) and some SAR processing.

NASA missions require processors that will work very reliably in a space environment. The higher data rates, increasing complexity, and greater autonomy require some very high performance processors. On-board computer systems for critical functions must be tolerant to Single Event Upsets (SEU) caused by high energy particles. Computer systems for missions in polar orbit and some planetary missions must operate reliably in high radiation environments. These requirements match closely, but not exactly, with many products being produced for DOD applicatons. The MAX computer is being developed as a consequence of work initiated to utilize DOD VHSIC devices in NASA on-board processors. The goal of VHSIC insertion into MAX has been delayed because VHSIC chip sets have not been available. The National 32000 series chips have been selected as an alternate to the VHSIC chips. The National chips are very attractive for use on NASA missions because of immunity to SEU and high radiation tolerance.

The work in process is concentrating on architecture development. That development is being done with commercial processor cards using 68020 processors until a National 32000 series chip set becomes available. The MAX computer can also be implemented using DOD VHSIC chips and that may be done when an attractive set of chips becomes available. The MAX architecture can be assembled with a mix of different kinds of processors.

TECHNICAL CONTACT: David Smith, JPL (818) 354-4480

MAX ARCHITECTURE

MAX ARCHITECTURE

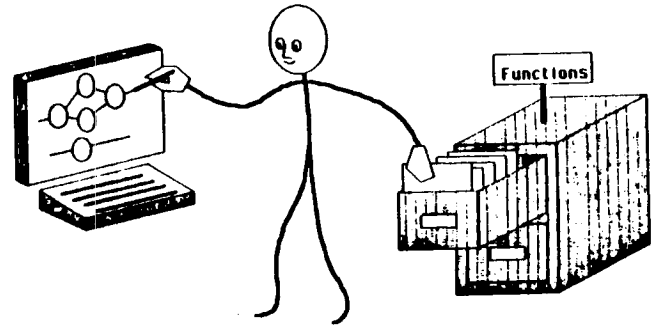
DATA FLOW ARCHITECTURE
- –MULTIPROCESSOR CONCURRENT PROCESS
- –DIRECTED GRAPH SYSTEM PROGRAMMING
- –ADA APPLICATION PROGRAMS

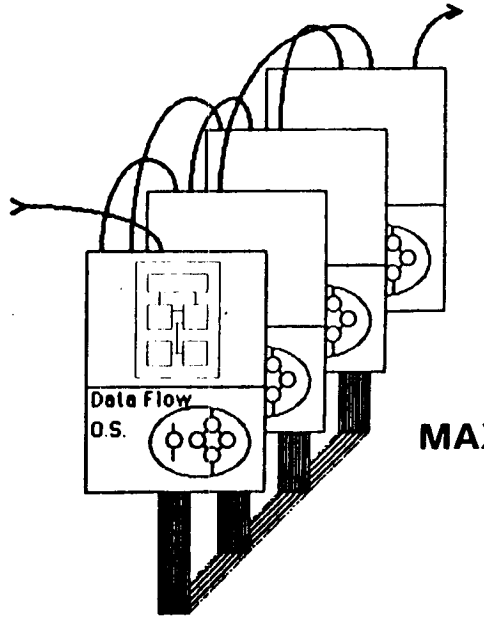
GENERAL PURPOSE APPLICATIONS
- –1 TO 11 MOPS COMPUTATION RANGE
- –1—300 MBPS I/O DATA RATES

POLAR ORBIT & PLANETARY
- –100k RAD HARD
- –SEU IMMUNE
- –10 YEAR OPERATION WITHOUT CRASH

DEMONSTRATION HARDWARE
- –NATIONAL NS32000 FAMILY NOW
  - –2 MICRON VLSI
  - –CMOS
- –WHEN AVAILABLE
  - –VHSIC
  - –GaAS

THE PROGRAMMER'S VIEW OF MAX





MAX HARDWARE

Advanced General Purpose Computer

In order to help meet the growing general purpose computing requirements of future space systems, work is underway to define a new computer with advanced architecture and device technology features suited to the particular needs of these systems. A typical early application might be the computing systems on the NASA Space Station, although many other potential users would be served as well.

Architectural studies have indicated that a loosely coupled, distributed control, concurrent processing system will best serve general requirements by providing flexibility in throughput, accommodation of a range of device technology speeds, and redundancy where necessary for fault and damage tolerance. The architectural thrust of this research effort has subsequently been focused on the development of a particular computer interconnection scheme and operating system which can exploit a low resolution, data flow approach to software concurrency.

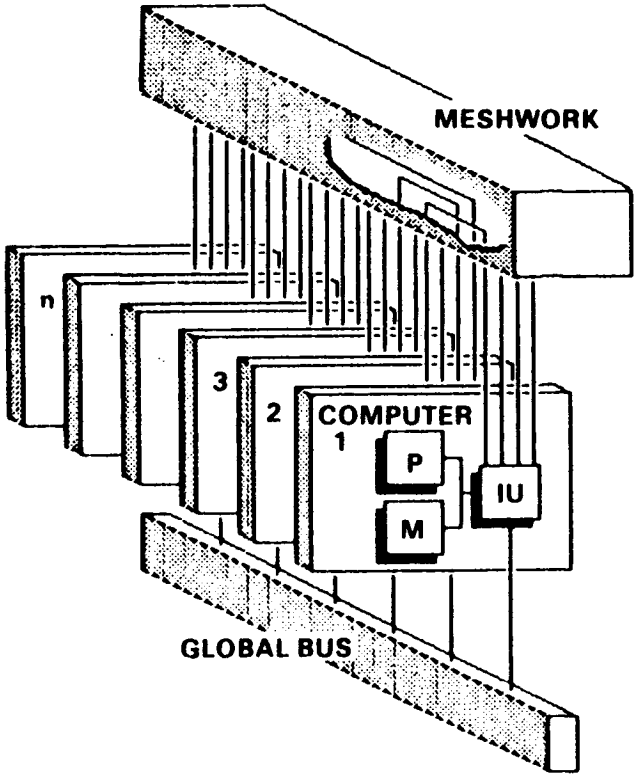
Data flow is the concept of controlling the flow of software execution via the availability of data as opposed to the more common approach of explicitly passing execution control from one program element to the next. The potential for concurrent processing under data flow is more easily expressed than with other forms and may be represented graphically as a directed graph which shows the flow of data between program elements. In a low resolution data flow system, the program elements of concern are complete routines (not simple instructions) programmed in conventional high level languages such as ADA, or HAL/S.

This new approach affords the opportunity to achieve efficient multi-computer utilization at lower hardware and software costs. It also provides a basis for the implementation in operating system software of a highly flexible fault and damage tolerance system with no additional hardware complexity. By performing data flow control via the operating system, concurrent execution and fault/damage tolerance are isolated from both hardware and application software design, thus representing no recurring cost to the system.

The objective of this work is to provide high performance processors for NASA on-board computers that are both reliable and affordable. Emphasis is being placed on coordinating this work with comparable DOD programs with particular emphasis on devices from the DOD Very High Speed Integrated Circuit program. Development work on architectures is underway, and these are being evaluated using processors which are not products of the VHSIC program, so the architecture work is not delayed by the availability of the VHSIC chip sets. The first set of VHSIC chips is expected in early 1986. Other VHSIC chip sets will be tested and evaluated as they become available.

TECHNICAL CONTACT: David Smith, JPL (818) 354-4480
Harry Benz, LaRC (804) 865-3535

ADVANCED GENERAL PURPOSE COMPUTER



SYSTEM ARCHITECTURE

- LOOSELY COUPLED MULTI-COMPUTER
- DATA FLOW CONCURRENCY
- SOFTWARE IMPLEMENTED FAULT TOLERANCE
- POINT-TO-POINT INTERCONNECTION MESHWORK
- SPECIALLY DESIGNED GLOBAL BUS FOR DISTRIBUTION PROCESS SYNCHRONIZATION

PAYOFF

- MUCH HIGHER PERFORMANCE THAN EXISTING SYSTEMS
- FAULT AND DAMAGE TOLERANT WITHOUT COMPLEX VOTING OR SWITCHING HARDWARE
- ON-LINE REPAIRABILITY FOR UNINTERRUPTED LONG-TERM SERVICE
- EFFICIENTLY ADAPTABLE TO A WIDE RANGE OF APPLICATIONS THROUGH INCREMENTAL EXPANSION

Spaceborne VHSIC Symbolic Processor

A major problem facing NASA is the increasing cost for the development, operation, and maintenance of large space projects such as the Space Shuttle, Space Station, Earth Observing System, and Mars Rover. The development and implementation of "intelligent" systems, of which expert systems technology is a key component, will contribute significantly to the reduction of human-intensive tasks related to mission operations, increase crew and scientific productivity, and reduce the documentation required for troubleshooting and diagnostics. Execution of the heuristics or rules for the "intelligent" systems will be accomplished by spaceborne symbolic processors.

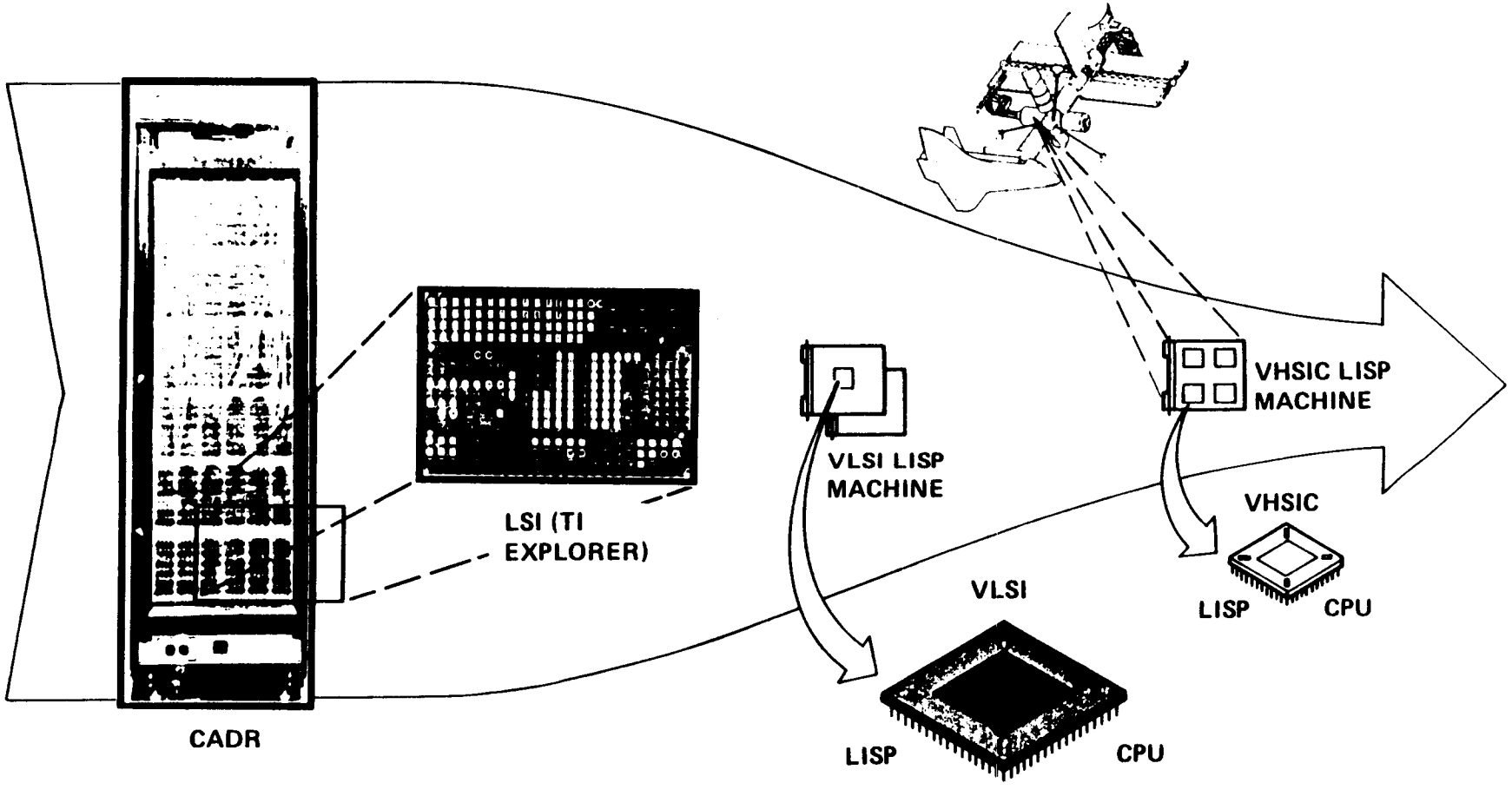
The objective of this program is to develop a spaceborne VHSIC symbolic processing system capable of handling a minimum of 22,000 rules with a minimum execution rate of 8,000 rules per second. The program objectives are to provide an architecture capable of handling the natural parallelism inherent in problems solved by humans and to develop a knowledge base processing algorithm capable of processing a large number of facts as well as an execution mechanism which supports the algorithm. The goal for radiation resistance will be a minimum of 10^5 rads. Algorithms for automated fault detection, identification, isolation, and correction are also included as part of the architecture design.

Several potential architectures are being evaluated and currently include Symbolics, Inc. (NASA), TI (DARPA), DEC (IR&D), and Stanford (NASA) (the funding sources are indicated in parentheses). Preliminary "standardized" test cases have been developed to evaluate the architecture's performance and are being refined as more data is obtained - test cases involve both numeric and symbolic functions. In addition, a generic distributed architecture computer model is being developed to simulate and evaluate technical tradeoffs associated with specific architecture designs. An unqualified brassboard version of the spaceborne VHSIC symbolic processor is expected during late 1989. Programming languages will include Common LISP, Prolog, and ADA.

TECHNICAL CONTACT: H. Lum, ARC (415) 694-6544

SYMBOLIC PROCESSOR EVOLUTION

SPACEBORNE VHSIC SYMBOLIC PROCESSOR



YEAR	1978	1984	1986	1989
SIZE REDUCTION	100%	25%	12%	10%
IC COUNT REDUCTION	100%	67%	20%	15%
POWER REDUCTION	100%	43%	20%	18%
PERFORMANCE INCREASE	1X	2-3X	6-8X	12-15X

Human Factors - Aeronautics

The objective of the Aeronautics Human Factors Program is to provide the research and technology base for solutions to the human problems impeding the growth and safety of air transportation. The program has three major thrusts: flight management, human reliability enhancement and human engineering methods.

The flight management thrust is aimed at developing an understanding of crew/cockpit/ATC (air traffic control) interaction that can lead to improved operational performance and capability of the National Airspace System (NAS). It includes the development of supervisory control methods and human/computer dialogue design methods that will enable the "electronic crewmember" and "glass cockpit" concepts, and the development of theories of human perception, cognition, action and crew interaction to enable the supervisory control techniques referred to above.

The goal of the human reliability enhancement thrust is to develop methods for improving the overall reliability of the crew/cockpit/ATC system. This includes: the identification of systematic causes of human error in the cockpit and in ATC through the Aviation Safety Reporting System; the identification and evaluation of the effects of fatigue and circadian desynchronosis on aircrews; and the development of comprehensive models of crew error and of methods for controlling the propagation of that error through the system.

The human engineering methods thrust is aimed at developing improved human aviation crew systems. This includes the development of: a fundamental understanding of the phenomenon of workload, improved techniques for measuring crew performance, methods for implementing biocybernetics into the cockpit and an improved simulation technology base.

PROGRAM MANAGER: Dr. Melvin Montemerlo
NASA/OAST/RC
Washington, DC 20546
(202) 453-2743

Aircraft Automation: Field Studies and Guidelines

Automation and the wide-spread application of microprocessor technology to aircraft cockpits is proceeding at a rapid pace because of several technical, economic, and safety benefits offered by its use. However, experience thus far with highly automated man-machine systems suggests that these benefits are not achieved without significant cost, and may, under some circumstances, be unattainable. The purpose of the present field studies was to evaluate two recent approaches to flight deck automation to determine desirable and undesirable features and characteristics thereof, and to gain insight into related issues, including training requirements and factors determining flight crew acceptance of advanced technology.

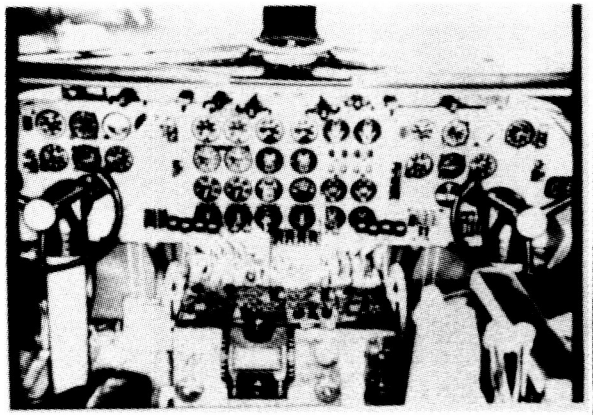
Studies were conducted during the early period of line operations of the McDonnell Douglas DC-9-80 (MD-80) and the B-767. The investigators attended ground school, observed line operations, administered questionnaires and rating scales, and interviewed pilots, check airmen, and instructors. A total of four airlines and their pilots participated in these studies.

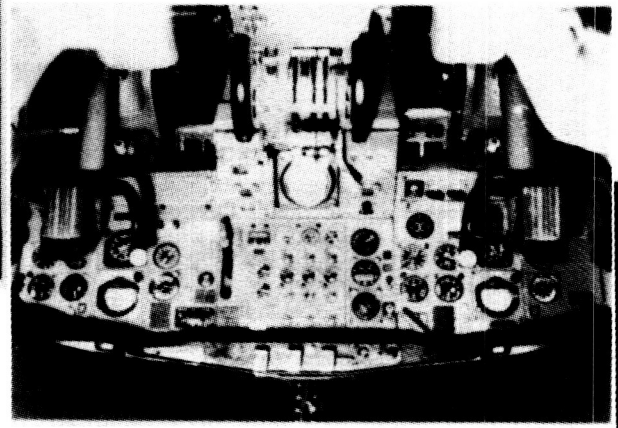
The results indicate widespread acceptance of the new cockpit technology by flight crews, although some specific design features are neither liked nor used. Significant improvements in training for the operation of the advanced cockpit systems is possible, and in some cases, certain design features and operating characteristics of these systems are not being adequately conveyed to the operators or their pilots. Improvements are possible in the way operational modes of certain systems are displayed to the flight crew, and in displays which indicate the status of separate but related systems, especially autothrottles and the pitch channels of the autopilot. Certain design principles or guidelines are proposed in the reports of these studies.

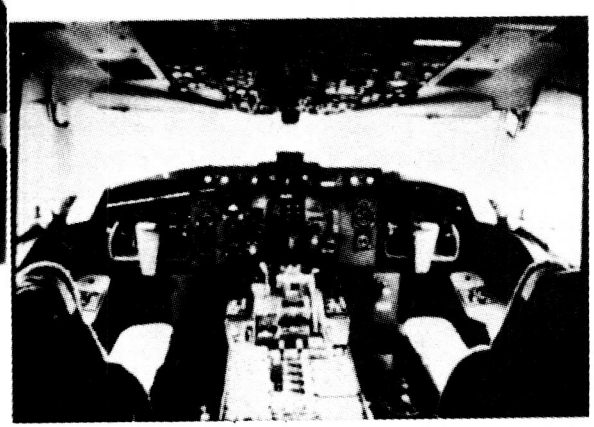
Two other reports were completed during the past year and were either published or are presently in press. Both review the development of aircraft automation, its effect or potential effects on reducing or changing pilot error, and suggest design philosophies for future automation systems to reduce the incidence or effects of pilot error.

TECHNICAL CONTACT: J. K. Lauber, ARC (415) 694-5717

FIELD STUDIES OF FLIGHT CREW TRANSITION TO ADVANCED TECHNOLOGY COCKPITS







OBJECTIVES

- DETERMINE PILOT ACCEPTANCE OF NEW COCKPIT TECHNOLOGY
- IDENTIFY UNIQUE TRAINING REQUIREMENTS
- IDENTIFY DESIGN ISSUES & GUIDELINES
- PROVIDE FEEDBACK TO OPERATORS & MANUFACTURERS

APPROACH

- SURVEYS & QUESTIONNAIRES
- INTERVIEWS
- COCKPIT OBSERVATION
- GROUND SCHOOL

OBSERVATIONS & CONCLUSIONS

- PILOTS ENTHUSIASTIC ABOUT ADVANCED COCKPIT TECHNOLOGY
- POTENTIAL SKILL LOSS CAN BE AVERTED
- THERE ARE UNIQUE TRAINING REQUIREMENTS
- IMPROVED DESIGN GUIDELINES ARE SUGGESTED

Intelligent Cockpits: Pilot-Matched CDU Organization

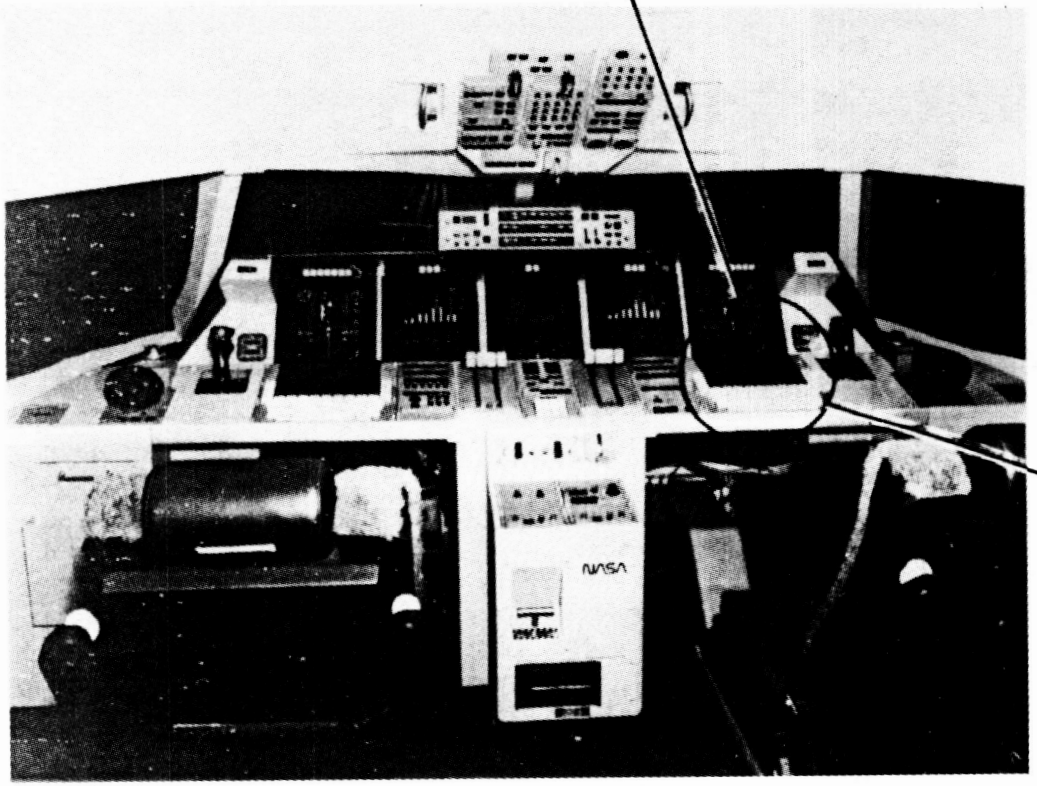
Advanced cockpits are notable for their lack of visual clutter and apparent simplicity when compared with older generation designs. This has been made possible by the use of multifunction/multiformat cathode ray tube (CRT) displays. Additionally, interactive computer systems have been introduced to automate certain of the pilot's tasks. While these advances are intended to improve the productivity and safety of flight management, pilots must now interact with onboard computers and search for information on programmable displays in order to use the automation designed to help them fly their aircraft.

The control display unit (CDU) is a computer terminal which is used to communicate with the flight management computers. Text information which appears on the CDU screen is arranged in pages that are accessed by keystrokes. Because there are many pages of information, the pilot must learn how to find the page of interest. Thus, the physical simplicity of the new cockpits introduces cognitive complexity, since the pilot must have a mental model of the paging structure in order to be an efficient user of the CDU.

To design paging structures which provide maximum efficiency, a technique has been developed at NASA-ARC to characterize the way pilots and CDUs relate flight management concepts. Given these relationships, the knowledge engineer can suggest ways to improve the ease of access to the information on the CDU pages. This has been done at ARC through experiments and network analysis to produce improvements in performance and reduction in training time.

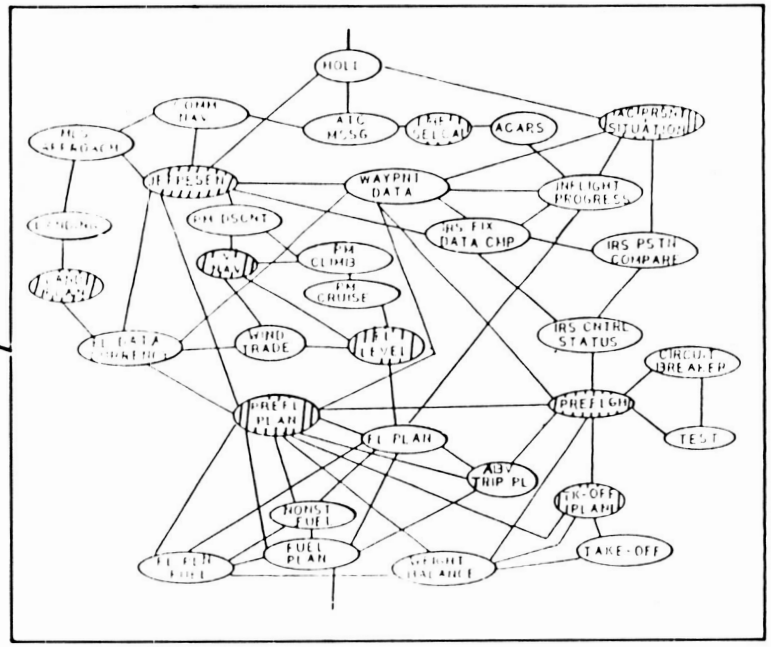
TECHNICAL CONTACT: Renate Roske-Hofstrand, ARC (415) 694-6147

INTELLIGENT COCKPITS: PILOT-MATCHED CDU MENU ORGANIZATION



OBJECTIVE

- DEVELOP PRINCIPLES FOR MENU ORGANIZATION TO REDUCE SEARCH TIMES AND ENTRY ERRORS



COGNITIVE NETWORK FOR PILOTS' CDU ORGANIZATION

APPROACH

- NASA/UNIVERSITY COLLABORATION
- MEASURE COGNITIVE ORGANIZATION/ REPRESENTATION OF CDU KNOWLEDGE FOR PILOTS USING COGNITIVE ENGINEERING TOOLS
- STRUCTURE CDU PAGE ORGANIZATION TO REFLECT PILOT ORGANIZATION
- COMPARATIVELY EVALUATE CDU USE IN MVSRF

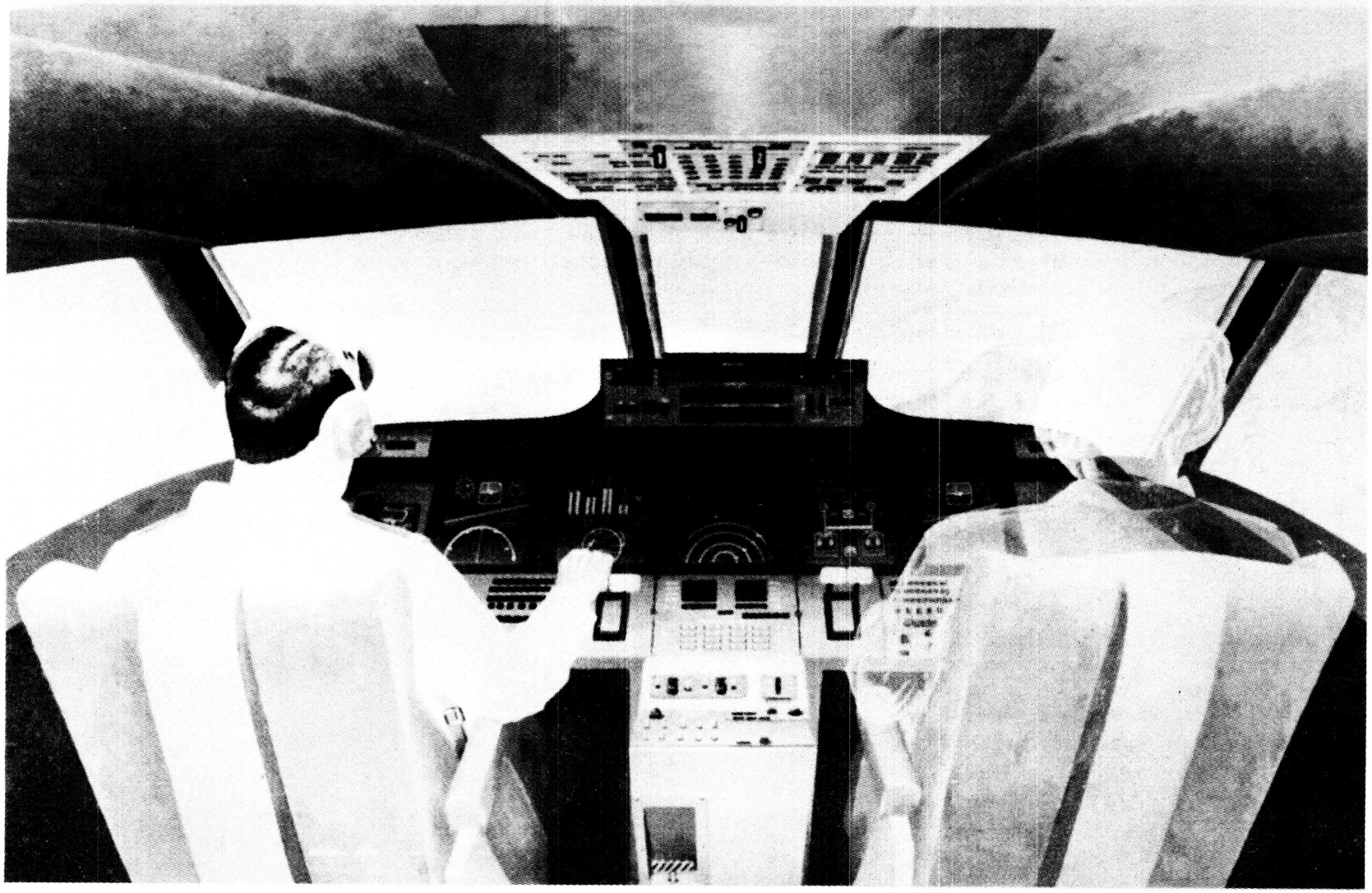
Artificial Intelligence Concepts for Flight Crew Aiding

Flight crews are required to operate aircraft in increasingly complex environments, and the trend has been to automate crew functions in order to alleviate crew workload. However, many crew functions are not amenable to conventional algorithmic techniques for automation. The recent advances in the field of artificial intelligence (AI) have shown that AI has potential for providing the technology for automated decision aids for which conventional automation technology is not suitable. The figure on the opposite page alludes to this situation. Some questions arise, such as, which crew tasks would benefit from the use of AI techniques; what are the human factors issues associated with the application of AI in the cockpit; what is the state of the technology in AI; and what areas of AI have potential payoff but require further research? A study was initiated to address these questions for civil transport aircraft.

An analysis of flight crew tasks was accomplished by extensively interviewing senior pilots from major airlines and from NASA. Based on the pilot interviews, several potential aids were identified. Included in this list of potential applications of AI were intelligent aids for: inflight fault monitoring, diagnosis, and reconfiguraton; navigation; communication; planning; crew/system interfaces; interface design; and proficiency maintenance. The human factors issues that were identified include: advisory versus actual control; crew interface, media, and adaptiveness; and potential skill losses.

TECHICAL CONTACT: Kathy H. Abbott, LaRC (804) 865-3621

ARTIFICIAL INTELLIGENCE CONCEPTS FOR FLIGHT CREW AIDING



The Causes and Effects of Runway Transgressions

The significance of runway transgressions is as much reflected by their frequency as by their consequences. This study attempts to uncover patterns of behavior that lead to these incidents by addressing questions such as: how often do pilots' or air traffic controllers' judgments contribute to the chain of events behind a transgression and, which errors, either judgmental or operational, have the propensity for snowballing into a runway transgression error?

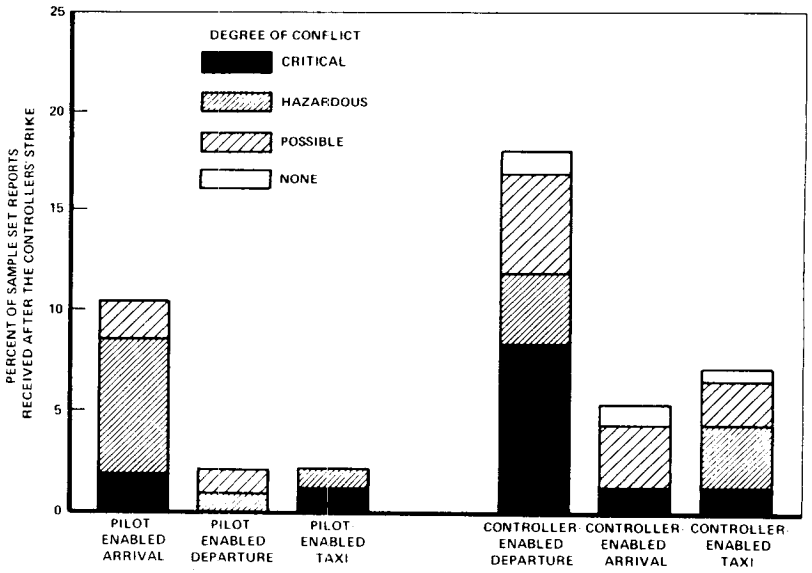
This research study, performed at the request of and in cooperation with the Federal Aviation Administration, took advantage of a vastly increased volume of Aviation Safety Reporting System (ASRS) event reports as well as a fully matured coding capability of the incident database. In the study, runway transgressions were categorized by phase of operation and enabling factor. Within each category, a quantitive assessment of risk was performed based upon the severity of observed consequences. In addition, the causal structure of each occurrence was modeled in terms of enabling factors linked to the a) chain of events and b) associated factors pertinent to the conditions that fostered errors or affected the severity of the consequences. The study concluded that controller-enabled transgressions during the departure phase show a significantly greater risk of collision than all other categories. Of lesser, but significant, importance are the risks associated with pilot-enabled arrival and taxi transgressions.

Although the controller-enabled departure transgressions yielded the highest risk level, it also showed the strongest correlations between causal factors. The most frequent errors precipitating this type of event were a controller's failure to visually locate traffic, his misjudgment of traffic spacing, and the failure to properly coordinate with other controllers. Each of these, however, was consistently associated with conditions of restricted visibility, the use of intersecting runways, and intersection takeoffs. Similar correlations were seen in other transgression categories. In summary, the study pointed to three general problem areas: information transfer, awareness, and spatial judgment.

TECHNICAL CONTACT: W. D. Reynard, ARC (415) 694-6467

THE CAUSES AND EFFECTS OF RUNWAY TRANSGRESSIONS
—A COOPERATIVE ASRS/FAA RESEARCH EFFORT—

- 23,391 INCIDENT REPORTS EXAMINED
- RUNWAY TRANSGRESSIONS IDENTIFIED AS A CONSISTENT AND GROWING HAZARD TO AVIATION SAFETY
- FREQUENCY AND CRITICALITY OF INCIDENTS CLOSELY ASSOCIATED WITH AIR TRAFFIC CONTROLLER ERROR
- INCIDENTS DURING AIRCRAFT DEPARTURE PHASE MOST FREQUENT AND MOST CRITICAL
- WILL RESULT IN MODIFICATIONS TO AIR TRAFFIC CONTROL PROCEDURES AND ENHANCED TRAINING TO ALERT BOTH CONTROLLERS AND PILOTS OF THE SEVERITY AND FREQUENCY OF FUNWAY TRANSGRESSION PROBLEMS



Pilot Performance Factors in Short-Haul Flight Operations: A Field Study

In-flight field studies were designed to document the psychological and physiological impact of fatigue and circadian factors on flight crews flying domestic short-haul and international long-haul trips. In addition, efforts are being made to identify those individual factors and behaviors which may exacerbate or moderate such effects in order to develop countermeasure recommendations for the aviation community.

Miniaturized solid-state technology is used to continuously record pilots' heart rate, body temperature, and limb activity before, during, and after flying line trips. Trip selections are based on factors such as the number of flights per day, trip and layover length, unusual flight times, high density airspace, and multiple time zone crossings. The physiological record is supplemented with time-linked cockpit observer logs of operational events per flight segment. Individual factors are documented by combining background personality and lifestyle information with daily logbooks in which each pilot's sleep, activities, diet, and mood are recorded.

Short-haul data collection has been completed with two East Coast carriers on 91 crew members on 46 trips (821 flights). Briefings on preliminary results have been presented to industry, pilot, and government (NASA, FAA, NTSB) representatives. Data analysis for the final report is in progress. Long-haul data collection was initiated in July 1985. The study will utilize four crews on each of six or seven representative trips in eastward, westward, and north-south directions. One eastward and three westward crews have been organized to date; participation by crew members is on a 100% volunteer basis. Completion of the data collection is anticipated about July 1986.

TECHNICAL CONTACT: R. C. Graeber, ARC (415) 694-5792

PILOT PERFORMANCE FACTORS IN SHORT-HAUL FLIGHT OPERATIONS: A FIELD STUDY

OBJECTIVES

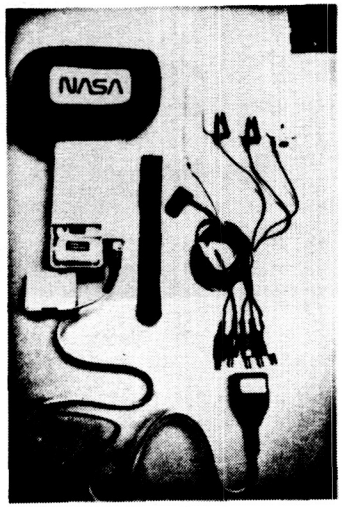
- DOCUMENT PSYCHOPHYSIOLOGICAL RESPONSES OF FLIGHT CREWS
- IDENTIFY PERSONAL ATTRIBUTES WHICH AFFECT CREW RESPONSE
- IDENTIFY INDIVIDUAL ADAPTIVE STRATEGIES IN USE

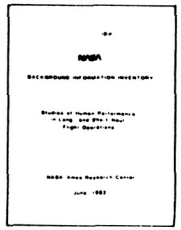
APPROACH

- CONTINUOUS MONITORING OF HEART RATE, TEMPERATURE, AND ACTIVITY
- DAILY SLEEP AND ACTIVITY LOGS
- QUESTIONNAIRES
- OBSERVER LOGS

OBSERVATIONS & CONCLUSIONS

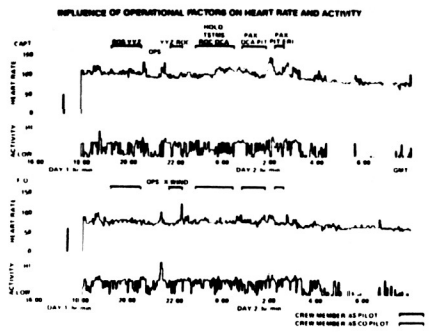
- SIGNIFICANT SLEEP DECREMENT DURING TRIPS
- SIGNIFICANT INCREASE IN SUBJECTIVE FATIGUE
- SIGNIFICANT CHANGES IN MOOD AND AFFECT
- UNEXPECTED CHANGES IN SLEEP/ACTIVITY AND TEMPERATURE RHYTHMS

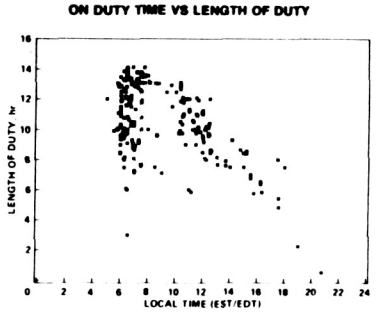




CONTENTS:

- DEMOGRAPHIC INFORMATION
- DIETARY HABITS
- FITNESS ASSESSMENT
- FLEXIBILITY OF DAILY HABITS
- SLEEP HABITS - HOME AND TRIP
- PERSONAL ATTRIBUTES QUESTIONNAIRE
- WORK AND FAMILY ORIENTATION QUESTIONNAIRE
- MORNINGNESS-EVENINGNESS QUESTIONNAIRE
- EYSENCK PERSONALITY INVENTORY





International Long-Haul Layover Sleep Study

The preliminary findings of a study to discover optimal methods for pilots and flight engineers who fly international routes to obtain proper sleep and rest during layover periods between flights have been completed. This study was coordinated by NASA-ARC and supported by scientists in W. Germany, England, Japan and the U.S.

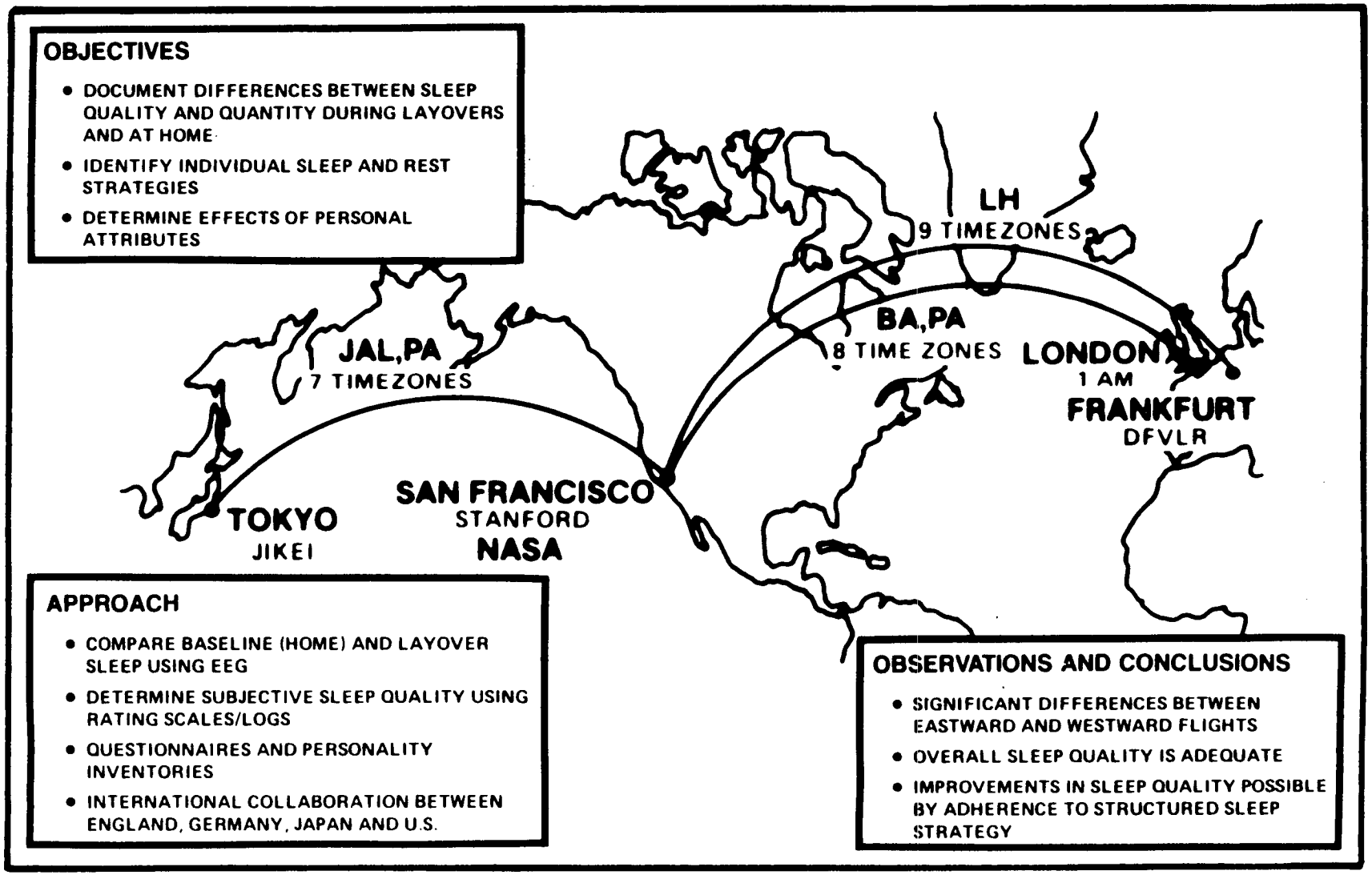
Through the support and cooperation of major international airlines and their flight crew members—British Airways, Japan Air Lines, Lufthansa, and Pan American World Airways—various objective and subjective measures of sleep quantity and quality were obtained from volunteer pilots and flight engineers who flew trips between their home bases and Tokyo, San Francisco, London, and Frankfurt. Instead of spending their layover nights in hotels, these crew members went to specially equipped sleep laboratories in each of the destination cities, where electrodes were attached to record electrical activity of the brain and other measures of sleep and waking activities. These recordings were scored by the scientists to determine the amount and quality of sleep obtained by the participating crew members, and to measure other relevant variables, including objective indications of the levels of sleepiness experienced by the participants during the following day and prior to reporting for duty to fly their next scheduled trip. These data were used by the scientists to determine the relative effectiveness of various "sleep strategies" such as napping or attempts to remain on home time instead of local time employed by long-haul airline crew members.

While most of the 56 volunteers obtained adequate sleep, major differences were noted between westward and eastward flights, an effect that is well-known to many long distance travelers. Based on the data obtained from this study, the scientists recommended that flight crew members could substantially improve the likelihood of getting "good" sleep during eastward layovers by adhering to a more structured sleep schedule, which should include deliberately limiting the amount of sleep taken immediately after arrival. This prolongs the subsequent wakefulness period during the local day, and thus helps to ensure that the major night sleep will be nearer to normal duration. The findings suggest that by optimally adjusting sleep using the preceding strategy, the sleep deficit which normally occurs should be minimized, thereby reducing sleepiness during the subsequent long return flight.

The data obtained from the study continue to be analyzed by the scientists for further information about the effects of other variables, including age and personality characteristics, upon layover sleep quality. The present study was limited to an examination of sleep quality during initial layovers. Follow-on studies are planned by the scientists to extend the findings to multiple layover flight schedules typically flown by international flight crews.

TECHNICAL CONTACT: R. C. Graeber, ARC (415) 694-5792

STUDIES OF LAYOVER SLEEP IN INTERNATIONAL LONG-HAUL FLIGHT OPERATIONS



Objective Assessment of Pilot Performance

The objectives of this program are to develop a series of short, full-crew, full-mission flight scenarios for use by researchers in the Man-Vehicle Systems Research Facility; to evaluate the scenarios during flight by experienced pilots temporarily placed at reduced levels of proficiency by drinking alcohol; and to collect a database of objective performance data that can be used to evaluate various measures of pilot performance in existence or proposed for use in subsequent investigations. Many measures of pilot performance have been used during the past three decades to assess the effect of a great variety of stresses on aircrew effectiveness. These measures range from very simple to very complex. Many appear to be highly correlated; most have been designed and applied under conditions where investigators had full knowledge of the circumstances of the experiment. There has been little or no systematic comparative study of the measures themselves. The Man-Vehicle Systems Research Facility (MVSRF) provides investigators with the opportunity to collect very large amounts of data in highly structured studies of aircrew behavior under tightly-controlled experimental conditions. The Facility is capable of producing far more data than can be effectively used unless automated, very efficient methods of data compression and reduction are applied. This study represents an attempt to develop and evaluate such measures, as well as to develop a library of standard scenarios which can be called upon by other investigators wishing to utilize the Facility's unique capabilities.

Eight scenarios (four transport flights in each direction between San Francisco and Los Angeles) have been constructed. The weather, routings, air traffic control complexity, anomalies and distractions have been chosen so as to produce approximately equal workload in the various scenarios. An experiment has been designed to present eight experienced air carrier pilots with each of the scenarios. Four levels of proficiency, induced by graded doses of alcohol, are utilized in the experiment, which is patterned on an earlier study conducted in general aviation aircraft in actual flight. Preliminary results indicate that the variability previously seen in flight is present in the performance of these pilots, notwithstanding their very high experience and their currency in the aircraft being simulated, a Boeing 727. Major errors by these pilots to date have been less than would have been anticipated based on the earlier flight studies. Data collection and compression techniques have been designed, coded and tested; they have also been found useful in other studies within the Facility. Data collection is continuing. Study of the data collected in this experiment may make it possible to characterize pilot and other aircrew performance automatically in near-real time. Such a characterization will in turn permit experimental conditions to be varied in real time in such a way that maximum experimental yield is gained more quickly and with substantially decreased expense to the investigators. It is thought that these data will also lead to better insights into the reasons for pilot and aircrew errors in the operational environment.

TECHNICAL CONTACT: C. E. Billings, ARC (415) 694-5718

OBJECTIVE ASSESSMENT OF PILOT PERFORMANCE

OBJECTIVES:

- PROOF TEST OF MVSRF FULL-MISSION SIMULATION CAPABILITY
- CREATION OF DATABASE FOR OFF-LINE TEST OF OBJECTIVE PERFORMANCE MEASURES

TASK

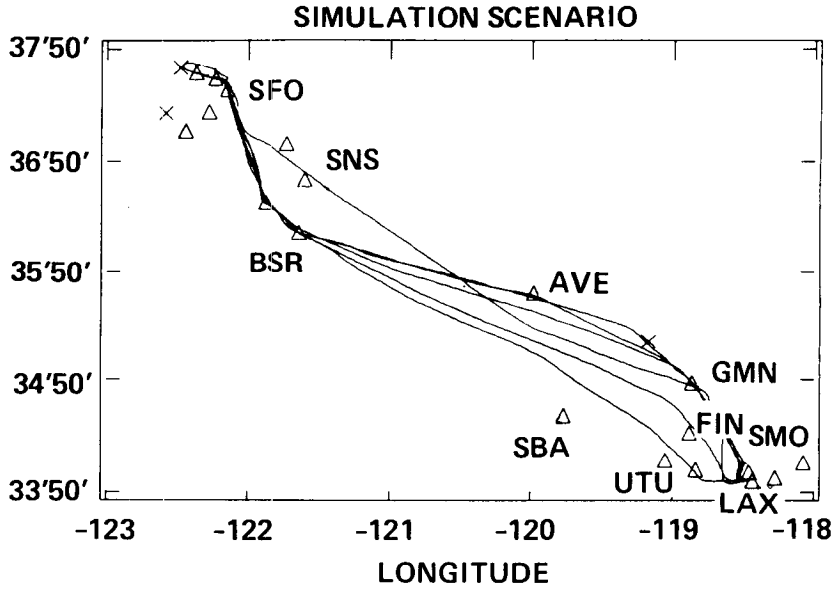
- EIGHT FULL-CREW, FULL-MISSION SIMULATED FLIGHTS BETWEEN SFO AND LAX

MEASURES

- ALL ASPECTS OF CREW BEHAVIOR

RESULTS TO DATE

- VARIANCE PREVIOUSLY OBSERVED IN SINGLE PILOT IN FLIGHT IS PRESENT, BUT
- MAJOR ERRORS FEWER THAN ANTICIPATED FROM SINGLE-PILOT DATA



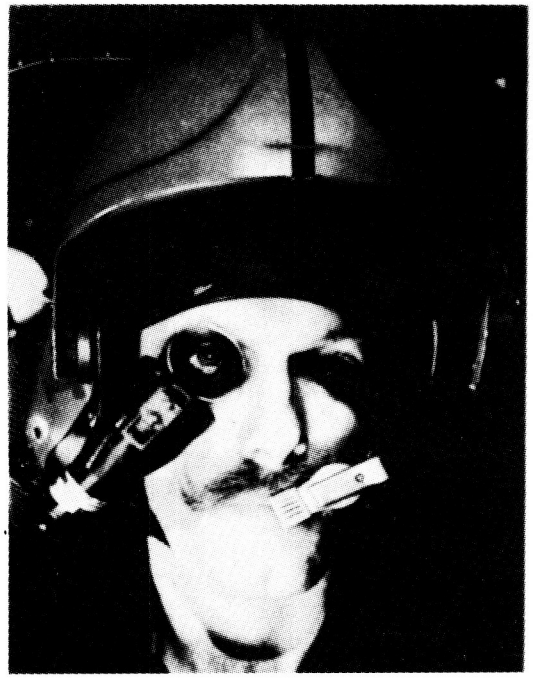
Development of Workload and Performance Assessment Methods

In order to evaluate pilot workload and performance, reliable and valid measures are required. The search for such measures was the initial focus of research for the Human Performance Assessment Research Group at ARC. Considerable progress has been made in this area through both in-house and the sponsored research of university collaborators. Five categories of workload assessment techniques have been investigated: primary task performance measures, secondary-task performance measures, physiological measures, subjective ratings, and task analyses. Within each category several promising measures were developed and evaluated. From this, the following measures have been recommended. For each of these measures, the types of workload questions for which they are particularly appropriate and the environments in which they can be applied have been identified. A summary of this research is being compiled in a NASA Technical Paper and coded into an "expert system" for workload assessment on a microprocessor for general distribution.

Many of these measures have been applied in operational environments at the request of organizations outside ARC (e.g., the U.S. Army). One example of such an experiment is the measurement of pilot workload, inflight, during training with the Pilot Night Vision System (PNVS). This research is being conducted in the Cobra Surrogate Trainer at Crow's Landing, California, in collaboration with the U.S. Army. The workload measures that have been developed and applied to this test include: inflight and retrospective pilot ratings, communications analysis, time estimation, heart rate, and heart rate variability.

TECHNICAL CONTACT: S. G. Hart, ARC (415) 694-6072

WORKLOAD ASSESSMENT IN OPERATIONAL SETTINGS



PREVIOUS MODELING AND TECHNIQUE DEVELOPMENT

- CRITERION TASKS FOR VALIDATION OF ASSESSMENT TECHNIQUES
- SENSITIVE SUBJECTIVE, OBJECTIVE AND PHYSIOLOGICAL MEASURES OF WORKLOAD

OPERATIONAL APPLICATIONS IN AERONAUTICS

- KUIPER AIRBORNE OBSERVATORY
- SCOUT II HELICOPTERS
- VMS EVALUATION OF SINGLE PILOT, SEMI-AUTOMATED NOE FLIGHT
- COBRA SURROGATE TRAINER, PILOT NIGHT VISION SYSTEM (PNVS)

- OBJECTIVE: DOCUMENT PHYSIOLOGICAL, PSYCHOLOGICAL EFFECTS OF PNVS TRAINING AND EVALUATE MODELS OF SKILL ACQUISITION
- APPROACH: 70 DAY/NIGHT FLIGHTS IN AH-15 COBRA SURROGATE TRAINER
- WORKLOAD AND PERFORMANCE MEASURES:
  - NASA BIPOLAR RATINGS
  - COMMUNICATIONS PERFORMANCE
  - HOVER AND BOBUP MANEUVER TIMING
  - HEART RATE AND VARIABILITY

Workload Prediction

The need to be able to predict the workload for new systems and system modifications during the initial design phase is even more critical to the operational community than workload assessment. To this end, a model for workload prediction has been developed. The initial model focused on general aviation flying under instrument flight rules. Three pilot opinion surveys were completed to obtain the data base. The rules by which the workload of complex tasks are predicted from information about the component tasks were developed in laboratory and simulation research. The initial predictions of the model have been tested in a number of simulation experiments using a motion base General Aviation Trainer. In every validation, the predictions of the model have been verified by a battery of workload assessment methods applied during the simulation flights.

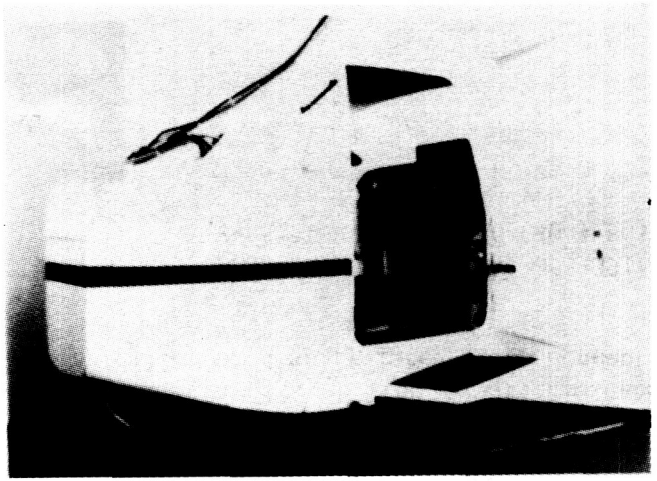
The general philosophy of the model is that pilots experience and evaluate the workload of flight segments with respect to previously experienced nominal flight segments. For these activities, information about the elemental task components is not relevant to the experience of workload, thus these over-learned, highly automatic sequences of activities are treated as a unit. During the conduct of any operational task, however, additional events occur that modify the level of workload that is actually experienced. The workload levels imposed by each of these and the rules by which their workload levels may be combined with that of the nominal segments vary, and have been developed through extensive empirical studies. This model allows system designers to create simulation scenarios that will impose known levels of workload and will provide a baseline against which modifications of system design can be compared with respect to their workload-impact.

The basic philosophy of the model will be applied to the following operational tasks in the coming year:

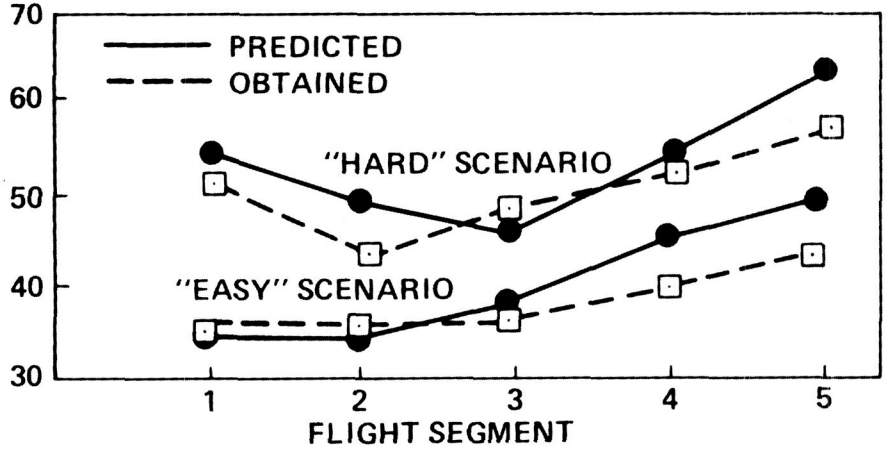
- Nap-of-the-earth missions for current and proposed Army helicopters
- Simulated helicopter flight in motion base simulators
- Remote manipulator arm operations in the Shuttle (STS) and Space Station

TECHNICAL CONTACT: S. G. Hart, ARC (415) 694-6072

WORKLOAD PREDICTION



OBTAINED VS. PREDICTED WORKLOAD LEVELS FOR TWO FLIGHT SCENARIOS



OBJECTIVES

- OBJECTIVE:
  - DEVELOP PREDICTIVE MODEL FOR CONSTRUCTING STANDARDIZED SIMULATION SCENARIOS
- APPROACH:
  - CONDUCT PILOT OPINION SURVEYS; DEVELOP PREDICTIVE MODEL; TEST MODEL PREDICTIONS IN GAT SIMULATOR
- RESULTS:
  - OBTAINED SUBJECTIVE AND OBJECTIVE MEASURES OF PILOT WORKLOAD CLOSELY MATCH MODEL PREDICTIONS
- OPERATIONAL APPLICATIONS:
  - PREDICT WORKLOAD OF SINGLE-PILOT NOE HELICOPTER FLIGHT IN VMS SIMULATOR
  - PREDICT WORKLOAD OF "GOVERNMENT" SCENARIOS FOR 5 ARTI/LHX CONTRACTOR SIMULATION EXPERIMENTS

Brainwave Measure Applied to Display Evaluation

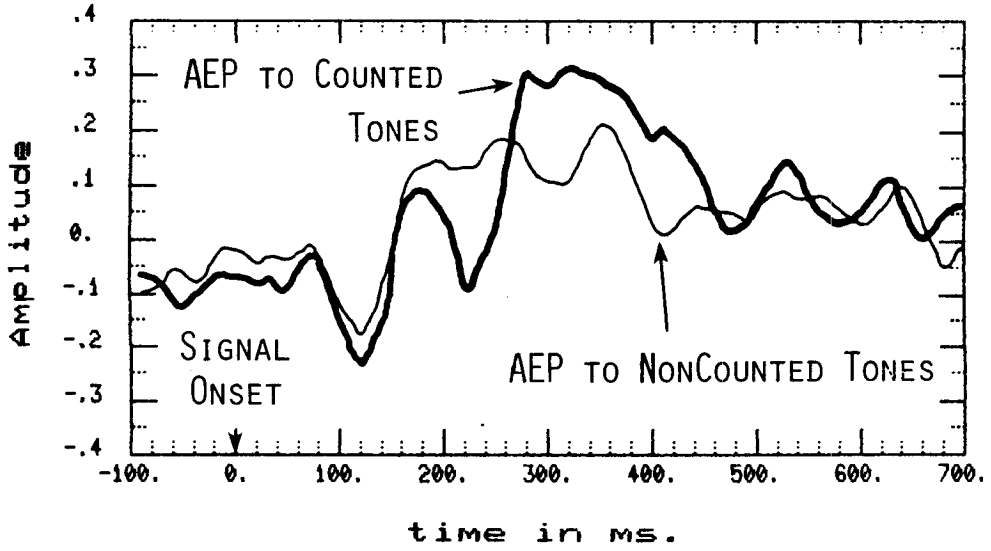
Because the nature of crew workload is significantly altered by emerging flight management concepts afforded by advanced crew station technologies, advanced human measurement techniques are required for their evaluation. An important evaluation consideration is the determination of differences in demand for crew mental resources imposed by these crew interface concepts.

One approach employed in this work involves examining the electrical activity of the brain for features that reflect mental resource expenditures. The transient cortical evoked response method—a technique for extracting information from the spontaneous brain activity—has previously been shown to exhibit features that reflect mental activity level.

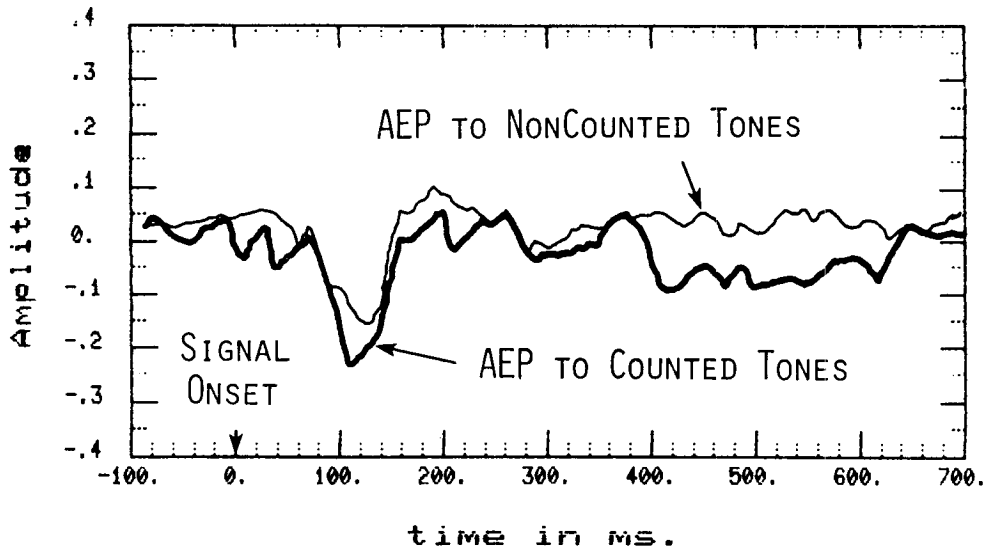
An evoked response procedure originally developed at the University of Illinois has been implemented at LaRC. A series of auditory tones are presented to the subject and the electrical brain responses to each tone is recorded. The subject counts the low-pitched tones within a series of both high- and low-pitched tones. When counting is the pilot's only task, the brain activity waveform peaks at about 300 milliseconds in response to the counted low-pitched tones, and not to the uncounted, high-pitched tones (upper panel of opposite figure). When the pilot is engaged in the flight task, the waveform does not exhibit the peak at 300 milliseconds in response to the counted tones (lower panel of figure). Thus, the technique reliably discriminates between task and no-task conditions; however, its potential value lies in its ability to discriminate gradations between these two extremes. The auditory evoked potential (AEP) response is currently being assessed for its ability to discriminate the different mental resource demands imposed by flight tasks performed using different display integration concepts.

TECHNICAL CONTACT: Alan Pope, LaRC (804) 865-3917
Randall Harris, LaRC (804) 865-3917

Mental Demand Effects on the Auditory Evoked Potential (AEP)



AEP when No Flight Task Is Being Performed



AEP when Flight Task Is Being Performed

Human Motion Model-Based Simulation Drive Logic

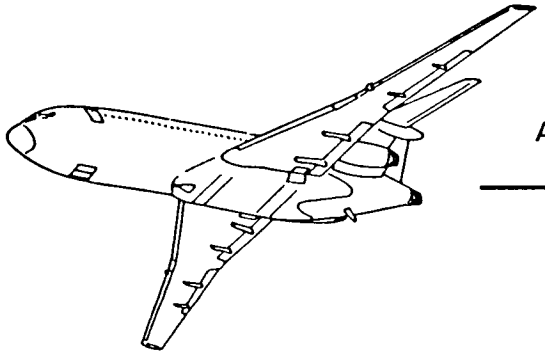
As the technology of flight simulators has advanced, they have become widely used in pilot training and certification. The issue of simulator fidelity continues to be a significant area of investigation, with tradeoffs being made between simulator cost and effectiveness. A large portion of the cost of a modern flight simulator is a result of the complexity of a six-axis motion platform. The research questions that must be addressed are: 1) how much simulator motion is needed to achieve a desired level of performance or transfer of training given a visual system of a fixed fidelity, and 2) is it possible to develop a set of motion control system design guidelines to achieve maximum fidelity?

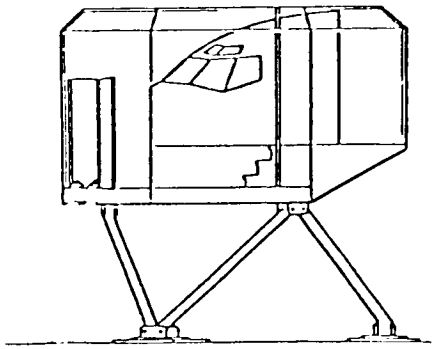
The approach taken involves the use of engineering models of basic sensory responses to changes in physical orientation occurring during flight, and the duplication of these responses during the external (visual) and motion capabilities of the simulator. The result should be an increase of the fidelity of the pilot's perception with the concomitant reduction in actual simulator motion and platform complexity. ARC has previously developed quantitative models for human spatial orientation based primarily on physiological models of the human vestibular system. Using these models to represent the dynamics of motion perception at the level of vestibular motion washout systems has been developed. Optimization theory was applied to minimize the vector error between the modeled vestibular afferent signals of the pilot of the actual aircraft and the pilot of the simulator. The optimization cost function included simulator motion constraints, so that the resultant control logic was consistent with the limits of a motion platform.

Initially, the work on the optimal washout design technique was extended by implementing it on the NASA Ames Research Center Vertical Motion Simulator (VMS). In a series of experiments, the optimal design technique for simulators having a large motion amplitude capability was generally validated. More recently, the vestibular models have been applied to the analysis of transport category flight simulators using the NASA MVSRF. The goal of this ongoing study is to utilize the vestibular modeling technique to generate a systematic means of evaluating the effectiveness of simulator motion platforms independent of their design. The resulting vestibular model metric will provide simulator designers and regulatory agencies with a common set of simulator motion requirements that are directly related to the perception of motion by the human pilot.

TECHNICAL CONTACT: A. Lee, ARC (415) 694-5937

HUMAN MOTION MODEL-BASED SIMULATOR DRIVE LOGIC





AIRCRAFT MOTION

SIMULATOR MOTION

MODEL OF HUMAN MOTION SENSATION

PILOT-WEIGHTED MOTION ERROR

SIMULATOR DESIGN OPTIONS FOR MINIMIZING MOTION ERROR

OBJECTIVE

- OPTIMIZE CURRENT TECHNOLOGY SIMULATOR MOTION FOR CIVIL TRANSPORT TRAINING AND ADVANCED ROTORCRAFT RESEARCH

APPROACH

- OAST-SUPPORTED M/T MOTION MODEL
- NASA UNIVERSITY COLLABORATION
- EXPERIMENTAL USE OF UNIQUE AMES SIMULATION CAPABILITIES

PAYOFF

- A DESIGN TOOL FOR:
  - OPTIMAL USE OF CURRENT SIMULATION TECHNOLOGY
  - GUIDELINES FOR NEXT GENERATION COST-EFFECTIVE MOTION SYSTEMS

Computational Vision Models

Vision is the primary information interface between the pilot and the aircraft and the pilot and the outside world. An understanding of human vision is critical to the design of effective displays and to the development of sophisticated, efficient machine vision algorithms. The latter may well provide the basis for future aircraft guidance systems or other types of advanced automation. The goal of this program is to develop advanced computational models of human visual processing, and to validate these models through experimental work with human observers. These models can then serve as the basis for applied research.

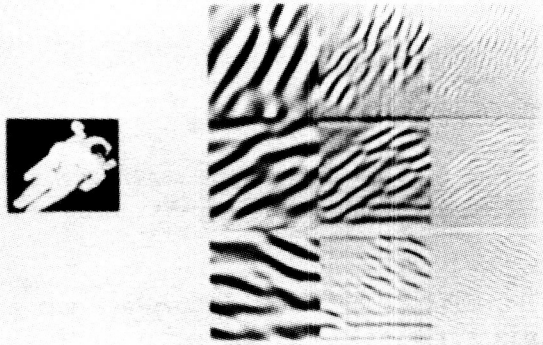
Recent accomplishments in this area include publication (in the Journal of the Optical Society of America) of a report on a model of human visual motion sensing. This model is capable of predicting human responses to arbitrary dynamic visual inputs, and will be tested against human performance in future work. A major revision of a previous model of spatial pattern vision has also been completed to include the spatial uncertainty of the observer. This work has resulted in two papers, also in the Journal of the Optical Society of America. A further development has been the successful transfer of major portions of the model code to the ARC supercomputer facility, and the installation of a high-speed network connection (VISNET) between the vision laboratories at ARC and the supercomputer network.

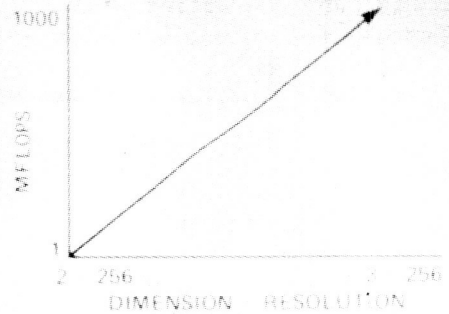
The models have provided the background for work in constructing an expert sytem for symbol and font design, image management research, and research on optimal color display guidelines and performance evaluation metrics for aircraft displays.

TECHNICAL CONTACTS: Andrew B. Watson, ARC (415) 694-6290
Kenneth R. K. Nielsen, ARC (415) 694-6290
Albert J. Ahumada, Jr., ARC (415) 694-6290

COMPUTATIONAL HUMAN VISION

PATTERN VISION

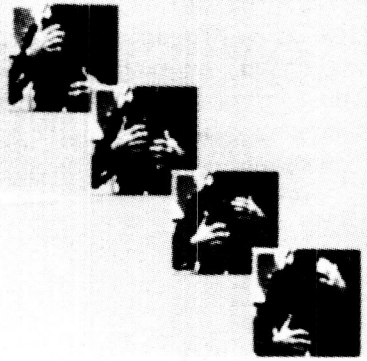


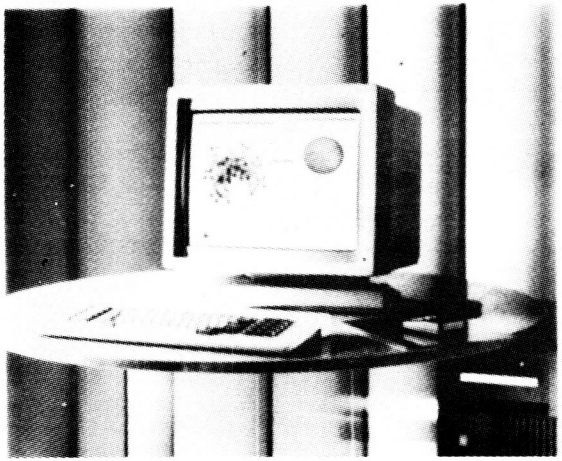


APPLICATIONS

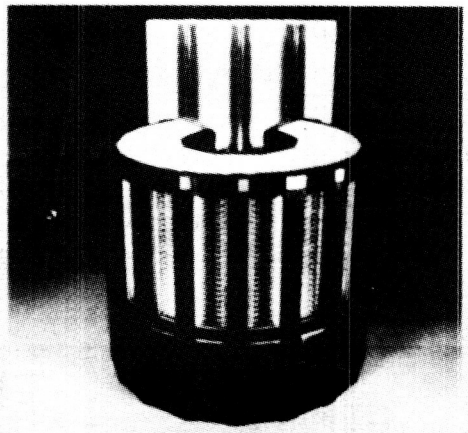
- ROBOTICS/MACHINE VISION
- DISPLAY DESIGN/EVALUATION
- IMAGE PROCESSING

MOTION





VISNET



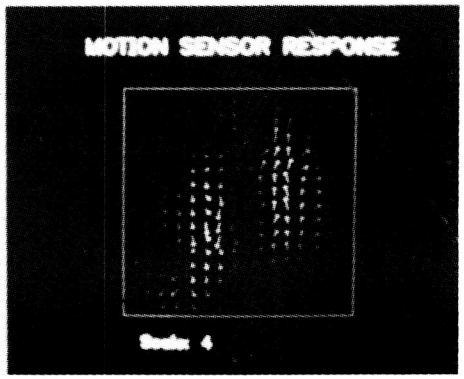


Image Sampling by Man and Machine

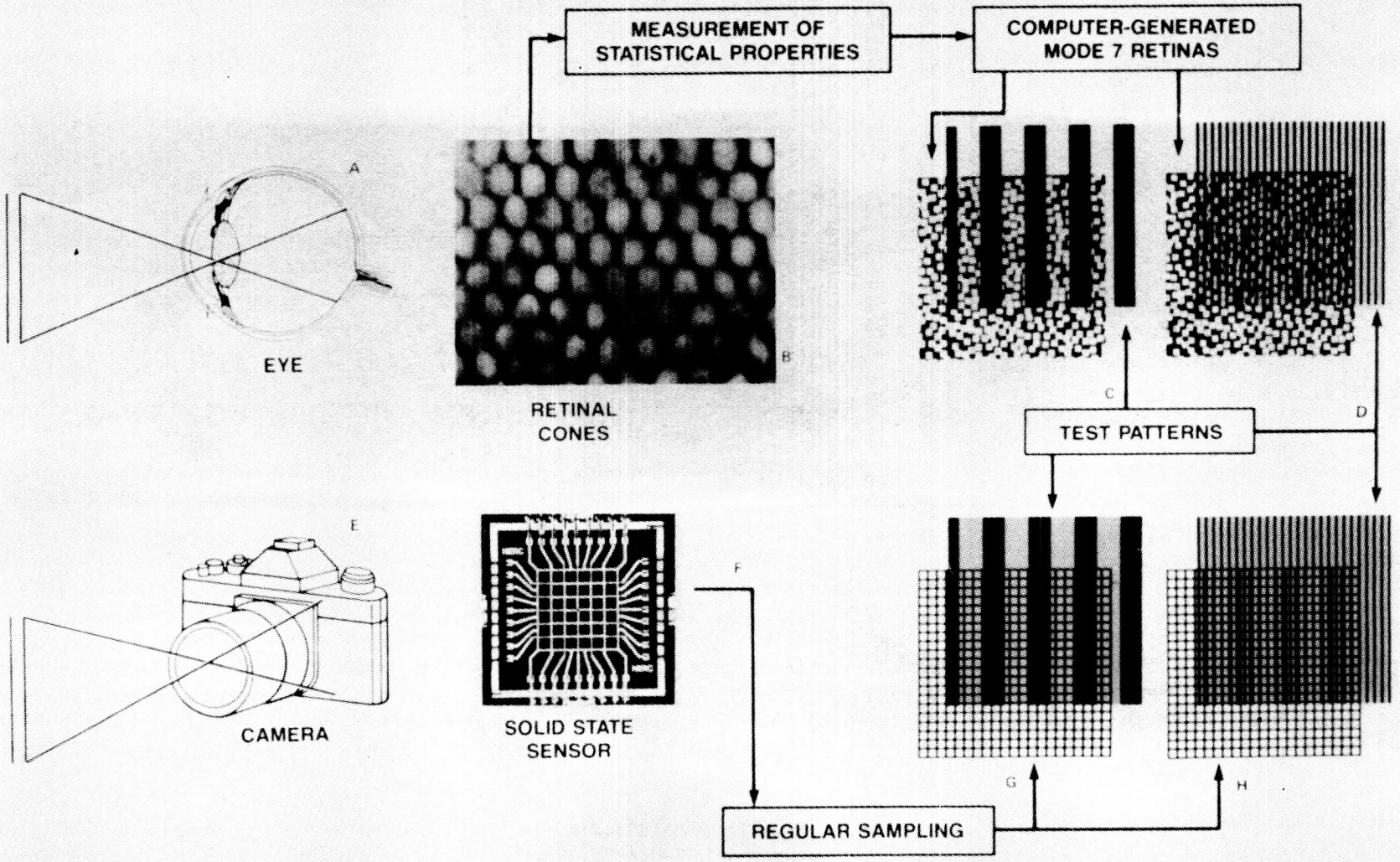
One feature of image acquisition and most display systems is the spatial sampling of the image. In systems with solid state sensor arrays or displays with finite picture elements (pixels) the sampling array is usually laid out in evenly spaced rows and columns. As long as there is at least one pixel per image "bar" or line, regular sampling is fine, but when there is more than one image bar per pixel, aliases or ghost bars appear. Under-sampling in the temporal domain can cause motion aliasing in a similar fashion.

In the human visual system, the cones are the elements of the sensor array. In the retina, the spacing of the cones is not regular, but looks like a sample from a constrained random process. The human visual system is effective at suppressing most forms of spatial and temporal aliasing; its performance provides several clues to the design of optimal dynamic flight displays. Statistical properties of the cone positions have been measured and computer programs developed to simulate retinal sampling arrays. As in the case of regular arrays, when there is at least an average of one sensor sample per image bar, the image is well reproduced. However, when there are multiple bars per sample, no ghost bars appear, just unstructured blotchy noise. Using quasi-random rather than regular sampling schemes thus can reduce the difficult problem of distinguishing ghosts from "real" image elements to the more tractable problem of ignoring random noise.

The image sampling research program is part of a general effort to make accurate models of the visual system to provide quantifiable predictions of human visual performance and to provide models to support the development of optimal visual displays. Work completed during the previous year showed the promise of stochastic sampling notions to reduce motion aliasing in dynamic flight displays. During the current year, work at ARC and at the University of California at Irvine has concentrated on developing accurate retinal statistics and sampling models. This work has led to "desert island" sampling schemes which allow the display designer to constrain the sampling noise to desired spectral regions.

TECHNICAL CONTACT: A. J. Ahumada, Jr., ARC (415) 694-6290

IMAGE SAMPLING BY MAN AND MACHINE



ACCOMPLISHMENTS

- BIOLOGICAL RETINAL SAMPLING HAS BEEN MODELED AS STOCHASTIC SAMPLING PROCESS
- STATISTICALLY OPTIMAL SAMPLING SCHEMES HAVE BEEN DERIVED

BENEFITS

- BETTER UNDERSTANDING AND PREDICTION OF HUMAN VISUAL PERFORMANCE
- IMPROVED IMAGE QUALITY AND MACHINE VISION SYSTEMS THROUGH STOCHASTIC SPATIAL AND TEMPORAL SAMPLING

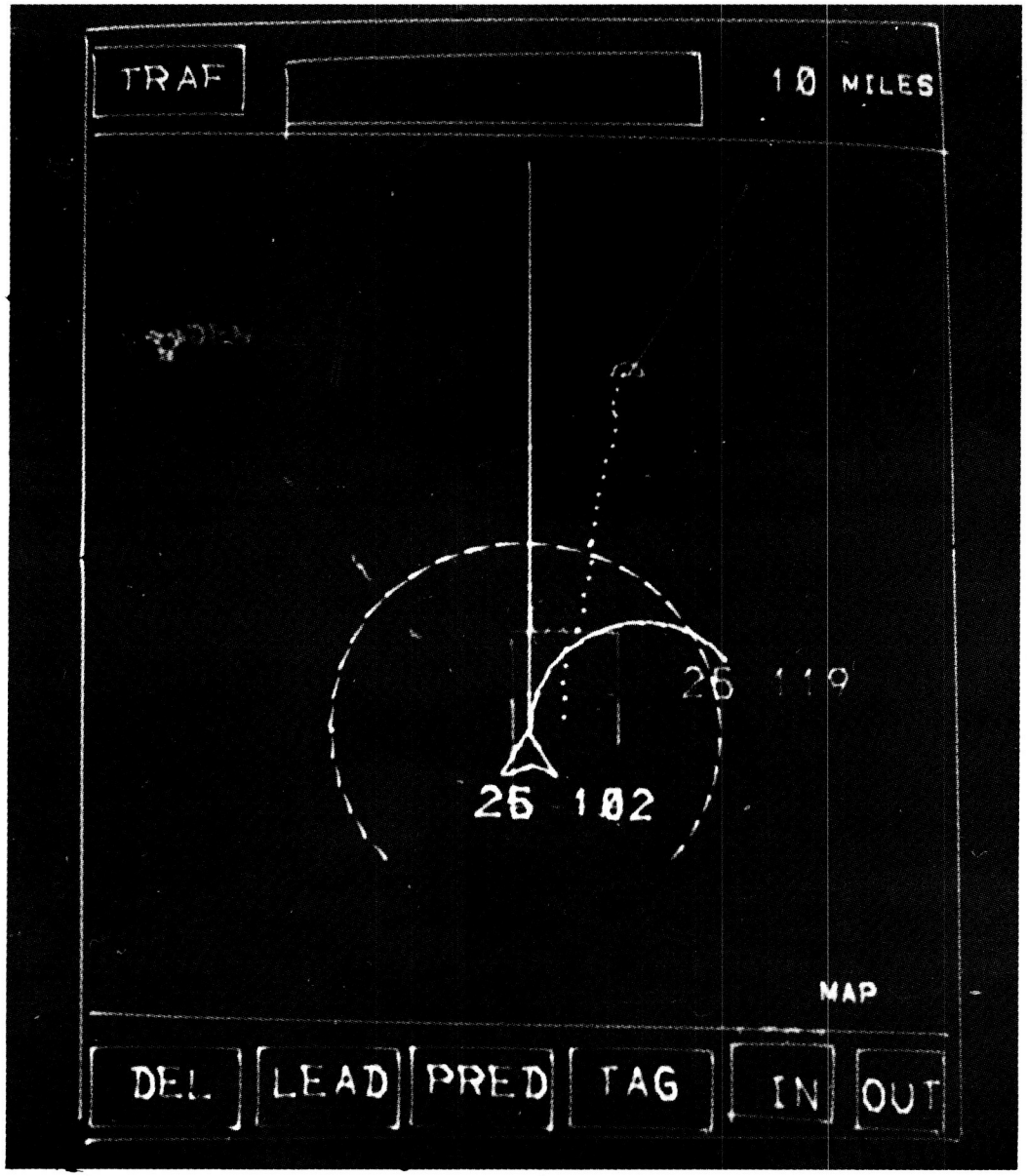
Cockpit Traffic Display Concept Tested in Conventional Jet Transport Simulator Under Instrument Workload Conditions

A series of CDTI (Cockpit Display of Traffic Information) experiments over the past several years has defined criteria for the various display-design parameters. Due to the part-task nature of those experiments, however, critical issues related to the effect of such a display (see opposite figure) on crew workload and overall system performance remained unresolved.

The current experiment, which involved eight flight crews from Republic and Eastern Airlines, was a full-system simulation of present-day jet transport operations in the Denver terminal area, utilizing the DC-9 full-workload cockpit and Mission Oriented Terminal Area Simulation (MOTAS) to provide a realistic ATC environment. On the positive side, the results indicated that CDTI was well received by the test subjects, with the workload increase associated with the CDTI-approach, self-spacing task being rated acceptable. Also, it was found that there was an improvement in arrival-time accuracy, accompanied by a 12-percent reduction in ATC communications. The latter condition indicates that the flight crews did not use the CDTI information as a basis for challenging/querying the ATC controller, which was an early concern. On the other hand, CDTI-induced distraction was further identified as a potential problem, highlighting the need for crew coordination and consistent operating procedures as important considerations. With the completion of the effort, now in the reporting stage, a good technical foundation exists for decisions related to implementation and utilization of CDTI.

TECHNICAL CONTACT: David H. Williams, LaRC (804) 865-3621

COCKPIT TRAFFIC DISPLAY CONCEPT



Army-NASA Aircrew Aircraft Integration (A^3I)

As advanced aircraft become more automated, more complex, and capable generally of higher performance, the pilot has become more and more the critical design and performance element within the overall system. Adequate human engineering of the design is too often ignored until latter stages of aircraft or systems development. To date, human factors has been an empirically-based discipline. Thus, until simulations of the vehicle under question can be developed, human engineering personnel must rely on handbooks, equipment design guides, or other compendia of human performance data. As automation technology evolves, much of the content handbooks or design guides become obsolete; human performance data in their raw form are notoriously difficult to translate into system design principles.

The A^3I program is an Army-NASA collaborative program that has as its goal the development of a human performance-based design and evaluation methodology that will enable the necessary human engineering steps to be taken early in the design cycle, and which will act to speed the human engineering design step by eliminating much of the need for empirical study of engineering trade issues. The program benefits from previous NASA-sponsored research on pilot performance and pilot modeling of human vision, motion sensing, manual control, workload, pilot error, and pilot information processing, and from broad expertise at NASA-Ames in information sciences, high speed computation, computer science, and simulation. Its ultimate goal is a rational design and evaluation tool that can be used directly by aircraft system designers; we have termed this tool "human computer-aided engineering," or H/CAE.

As currently envisioned, the H/CAE system will consist initially of six components: an automated mission planning system ("Mission Planner"); a set of graphics-based flightstation definition, representation, and layout tools ("Designer's Workbench"); a knowledge-based system that will allow the system training requriements to be estimated early in the design cycle ("Training Expert"); a generic vehicle simulation and modeling tool ("Vehicle Simulator"); a set of computational experiments and evaluations of the vehicle ("Model Pilot"); and finally, an Executive Control system to integrate the various components into a useful engineering tool.

The program began in FY84 with the development of an automated mission planning system appropriate to the helicopter NOE flight mission. During FY85, work was initiated on the development of "Training Expert" and on the specification of a distributed computing system that will be required to support the computational components. A survey of available CAD systems to support the "Designer's Workbench" development has been performed and a systems specification is currently being developed. Finally, the National Research Council Committee on Human Factors has agreed to sponsor a series of workshops (starting in early FY86) on the topic of the uses and usefulness of quantitative human performance models in human engineering activities. As initially planned, the A^3I program will be a six-year program. During its third year, ARC intends to initiate a series of industry internships that will support participation of selected helicopter designers in the A^3I development process. This activity should encourage and hasten the transfer of technology to industry.

TECHNICAL CONTACT: D. C. Nagel, ARC (415) 694-6170

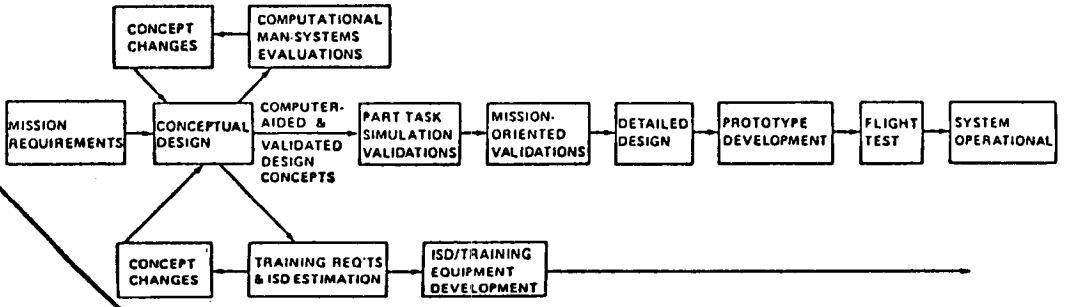
ARMY-NASA AIRCREW AIRCRAFT INTEGRATION PROGRAM (A^3I)

THE NEED FOR HUMAN COMPUTER-AIDED ENGINEERING

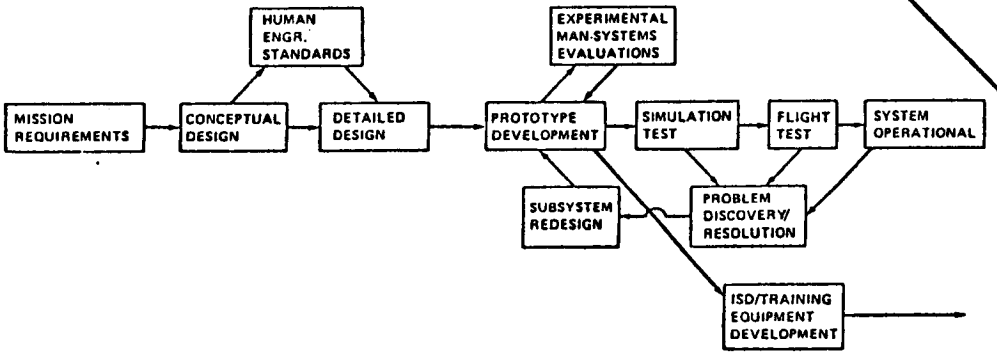
PROBLEM

- EXCESS COMPLEXITY
- LATE DISCOVERY OF FUNDAMENTAL FLAWS
- UNCOUPLED AIRCRAFT DESIGN, ISD
- TECHNOLOGY OUTSTRIPS HF KNOWLEDGE BASE
- REDUCED MISSION PERFORMANCE
- HIGH COST

COMPUTER-AIDED FLIGHT STATION DEVELOPMENT PROCESS



CURRENT FLIGHTSTATION DEVELOPMENT PROCESS



PAYOFF

- IMPROVED MISSION PERFORMANCE
- REDUCED DEVELOPMENT TIME
- REDUCED DEVELOPMENT COST
- REALISTIC, AFFORDABLE TRAINING SYSTEMS

Crew Station R&D Facility

The United States Army and NASA-Ames Research Center have entered into a joint agreement to develop a crew station research and development simulation facility (CSRDF). The purpose of the facility is two-fold: the first is to enable the Army to quantify mission performance differences between one-pilot and two-pilot LHX scout/attack helicopters; the second purpose is to support Army and NASA research and development programs for rotorcraft advanced technology.

The simulator is mission-oriented and features extensive and unique capabilities to simulate rotorcraft military scenarios, the military environment, and mission equipment that is interactive with this environment. The pilot interface systems are key to the concept and include a helmet-mounted display with head-directed field of view, full color, overlayed symbology and two-eye binocular vision, and an interactive "glass" cockpit that includes voice I/O, sound, touch screen CRTs and programmable switches. The CSRDF simulator (see opposite figure) has completed preliminary design and is scheduled for first operation in late 1986.

TECHNICAL CONTACT: A. D. Jones, ARC (415) 694-4027

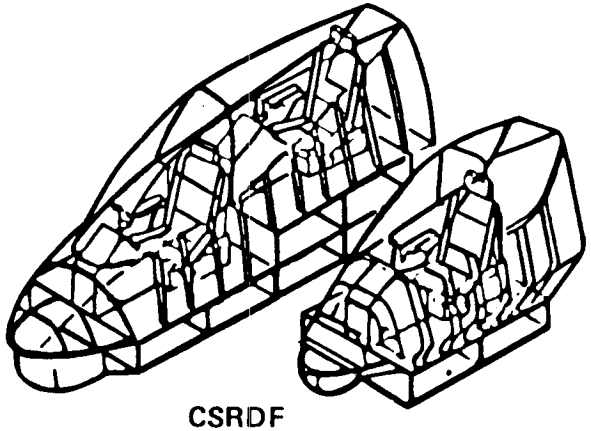
CREW STATION R&D FACILITY

OBJECTIVES

- QUANTIFY MISSION PERFORMANCE DIFFERENCES FOR ONE VERSUS TWO-MAN LHX SCAT
- SUPPORT ARMY/NASA RESEARCH (eg. SAINT) AND ARMY DEVELOPMENT (eg. LHX)

APPROACH

- MISSION–ORIENTED SIMULATOR
  - COMBAT MISSION SCENARIO/CAPABILITIES
  - SYSTEMS/MEP/ENVIRONMENT MODELLING
  - HELMET MOUNTED, HEAD DIRECTED DISPLAY
  - INTERACTIVE "GLASS" COCKPIT
- INTEGRATE HUMAN FACTORS AND SYSTEMS WORK



CSRDF

University Centers of Excellence

A longstanding problem in the successful application of human factors principles to aerospace problems has been the lack of personnel trained in a sufficiently broad range of relevant skill areas. Specifically, human factors personnel working on the development of complex aerospace systems require technical and engineering skills, computer and information science, behavioral science backgrounds, and content knowledge. Traditional university training programs rarely, if ever, prepare new researchers with this broad set of foundation capabilities.

OAST explicitly recognized this problem in FY83 by allocating funds to develop two University Centers of Excellence. One of these, the NASA Center of Excellence in Man-Systems Research at the University of Michigan, has been developed primarily as a training center. It is associated with the University of Michigan Transportation Research Institute and currently supports eight superior graduate students from a number of departments and disciplinary programs. Supporting the Michigan Center are a number of distinguished faculty members with affiliations in engineering, psychology, ergonomics, and computer science.

The second NASA Center of Excellence is at Stanford University. Here, the orientation is on the development of cooperative research programs between Stanford faculty and NASA research scientists, with the multi-disciplinary training of students and postdoctoral associates a by-product of the research collaboration process. Currently, six distinguished members of the Stanford faculty are participating, including three members of the National Academy of Science. The first full year of activity at the Stanford Center has seen the acquisition and use of an IRIS workstation and several collaborative research programs, even though three of the six Stanford faculty were away from the campus on sabbatical leave. It is anticipated that significant increases in the research activities will take place during FY86.

TECHNICAL CONTACT: D. C. Nagel, ARC (415) 694-6170

Human Factors - Space

The objective of NASA's Space Human Factors Research Program is to provide a technology base for effective use of crew system automation and improved productivity of human operators, allowing a reduction of excessive support personnel, while maintaining a high level of operational safety.

The appropriate functional allocation and interface between humans and highly automated systems continues to be a major thrust of the program. As computer techniques and facilities rapidly advance, new human factors concerns arise. For example, sophisticated space and support systems are capable of increasingly intelligent behavior. This advanced form of automation creates a system with distributed goals and decision makers. Further, new interface methods, like voice and pictorial interaction, are providing opportunities for more natural system operation. As a result of this progress, the tools of space human factors must be continually advanced so that highly automated systems can achieve their potential for efficiency and safety.

Image data displays and pictorial instruments are very high bandwidth information interfaces with potential for rapid communication. Space traffic control, teleoperations, monitoring of autonomous vehicles, systems monitoring, and data handling will benefit greatly from advanced displays. Human factors research is providing well-quantified models and design specifications so that the fast, accurate information transfer between the system and the user is assured.

The quality of space station operations will be profoundly influenced by workstation arrangement, the workload imposed by system design, and crew performance. To address these complex issues, human factors researchers are developing new analysis tools, design requirements, and performance measures. Since the Space Station will have a novel configuration of task locations and worksites, a new operations simulator is being developed to help in the analysis of their arrangement. To help ensure that the task environment is compatible with human physical constraints, a sophisticated laser anthropometry system is under development. The addition of motion and strength data derived from typical tasks will increase the utility of the anthropometric modeling system.

Extra-vehicular activity (EVA) will be more productive in the near future because of developments in space suits, power assisted glove end-effectors, space helmet displays, and improved EVA workstation/restraint systems. With advanced hard space suits, astronauts will be able to don their suits and exit the spacecraft without time-consuming pre-breathing. The requirements of these suits, which include comfortable mobility, greater hand dexterity, and very high reliability, have demanded improved materials, manufacturing and testing.

Space human factors research directly supports NASA's goals in space by ensuring that manned space systems are highly productive. This is accomplished by focused analysis of essential design and performance issues concerning the interface between advanced automation and human operators.

PROGRAM MANAGER: Michael W. McGreevy
NASA/OAST/RC
Washington, DC 20546
(202) 453-2744

HORSES: An Expert System for the ORS

A central part of the ARC effort in the area of Systems Autonomy is to define improved operator interface requirements. Since the theoretical procedure to do this is not well understood, an expert system "test bed" was developed to support the required studies. ARC decided to develop an expert system that supports operator assisted fault diagnosis of a dynamic system. The primary benefit of this choice is that experience can be gained with an on-line system operating in parallel with a realtime simulation of an operational system. Most expert systems are off-line advisory or planning systems, for which response times are of minimal importance. The experience gained will be valuable in the development of new generations of expert systems used in automating dynamic subsystems for advanced space systems.

The Orbital Refueling System (ORS) was chosen as the target dynamic system. The ORS is a system designed to be flown in the cargo bay of the Shuttle to replenish the hydrazine supply of orbiting satellites. A schematic of the system is shown in the center of the opposite figure. A mathematical model of the ORS was obtained from the Johnson Space Center. Documentation also supplied by JSC provides detailed fault diagnosis procedures and rules representative of those typically used by ground or shuttle operators of space systems when malfunctions occur. The malfunction diagnosis rules contained in the documentation became the primary rule-base for the Human Orbital Refueling System Expert System, or HORSES.

HORSES consists of three interactive rule bases. The first of these comprises about 250 rules, derived from the above-mentioned diagnostic procedures. The second consists of "meta-rules" or heuristics, derived from the primary rule-base and operating procedures. This second rule-base is used in some cases to speed the diagnostic process by reducing the efective number of rule chains that must be searched. The third rule-base is a set of conditional rules that is used by the HORSES inference engine to recognize patterns of information concerning ORS performance and to elicit the appropriate metarules. HORSES thus uses advanced techniques beyond those typically found in commercial, expert system "shells" to create a fast system capable of working on a relatively large rule-base and yet maintain acceptable real time response.

HORSES currently is implemented as an on-line aid to the operator. With relatively straightforward enhancements, it can also be made to serve as an automatic diagnostic system. As such, it will support future studies of human operator interaction with increasingly advanced forms of automation. Experiments are now being conducted to determine the adequacy of the "explaining facilities" of HORSES, and to assess the suitability of the existing graphical interfaces.

TECHNICAL CONTACT: E. A. Palmer, ARC (415) 694-6073

SPACE AUTOMATION: INTELLIGENT OPERATOR AIDS

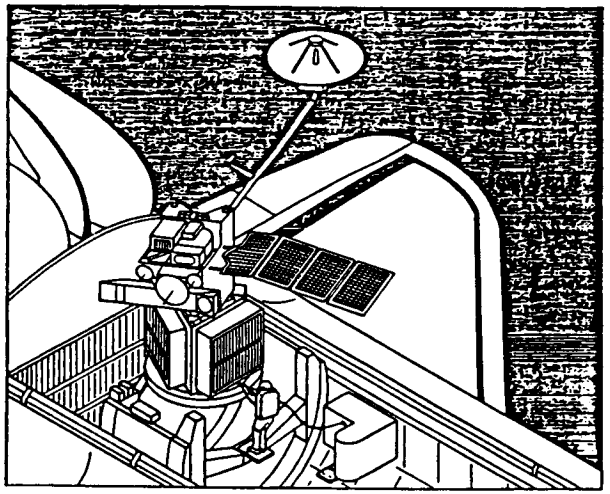
HORSES: AN EXPERT SYSTEM FOR THE ORS

OBJECTIVE

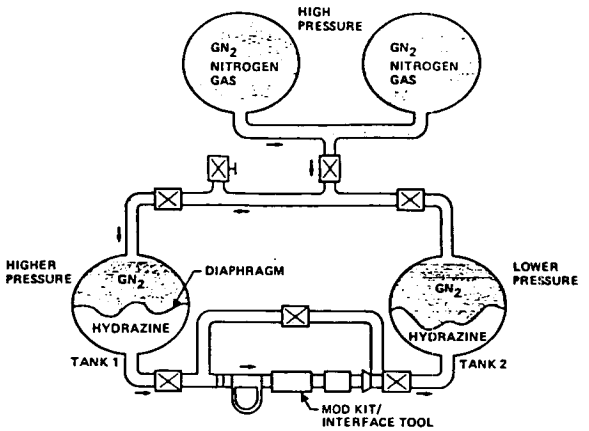
- FAULT DIAGNOSIS AID FOR ORS OPERATORS
- EMPIRICAL METHODS FOR EVALUATING INTERACTIVE SYSTEM PERFORMANCE

FEATURES

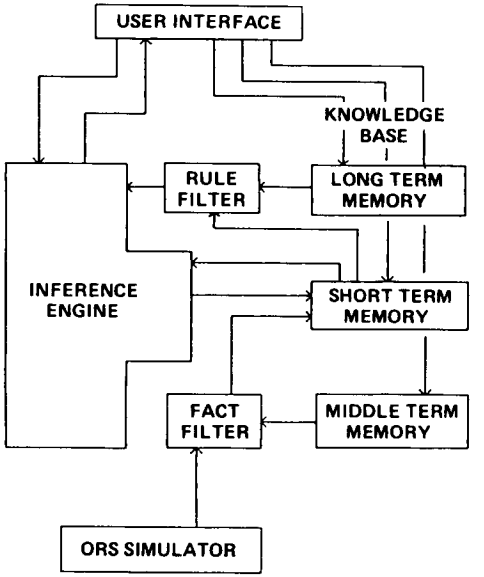
- EXPLAINS REASONING
- DYNAMIC DATA SOURCE
- TOLERANCE FUNCTIONS—FUZZY LOGIC
- GRAPHIC INTERFACE
- BASED ON KNOWN MALFUNCTION PROCEDURES



ORBITAL REFUELING SYSTEM
REFUELING LANDSAT-D



ORS SCHEMATIC



HUMAN ORBITAL REFUELING
SYSTEM EXPERT SYSTEM

Intelligent Operator Aids: Operator Task Models

New forms of automation are being designed which can greatly improve overall performance levels of operators of ground and space systems. For example, decision-aiding automation will provide knowledge so that human decision makers may optimally benefit from past experiences. Such systems will also support decisions by reasoning from rulebases and from quantitative and qualitative models of systems and the environment. For systems that are less than fully autonomous (that is, a human operator monitors and supervises system operation somewhere within the system), such systems must explicitly be designed with human operator capabilities and limitations as information processing systems in mind. Automation may have at least two roles here. First, it can be used to effect an "interface agent", that is, a system which has the express purpose of managing the flow of information between the system and the human operator. The result can be adaptive information (e.g, display) systems which modify displayed information based on the current system state and operator goals. Such systems will maximize operator productivity and minimize human error that is based on information overload or poor information presentation. Other forms of automation will "understand" operator decisions and actions (through representation of operator goals, system protocols, and system models) and will detect - and in some cases correct - operator errors of the procedural or decision variety.

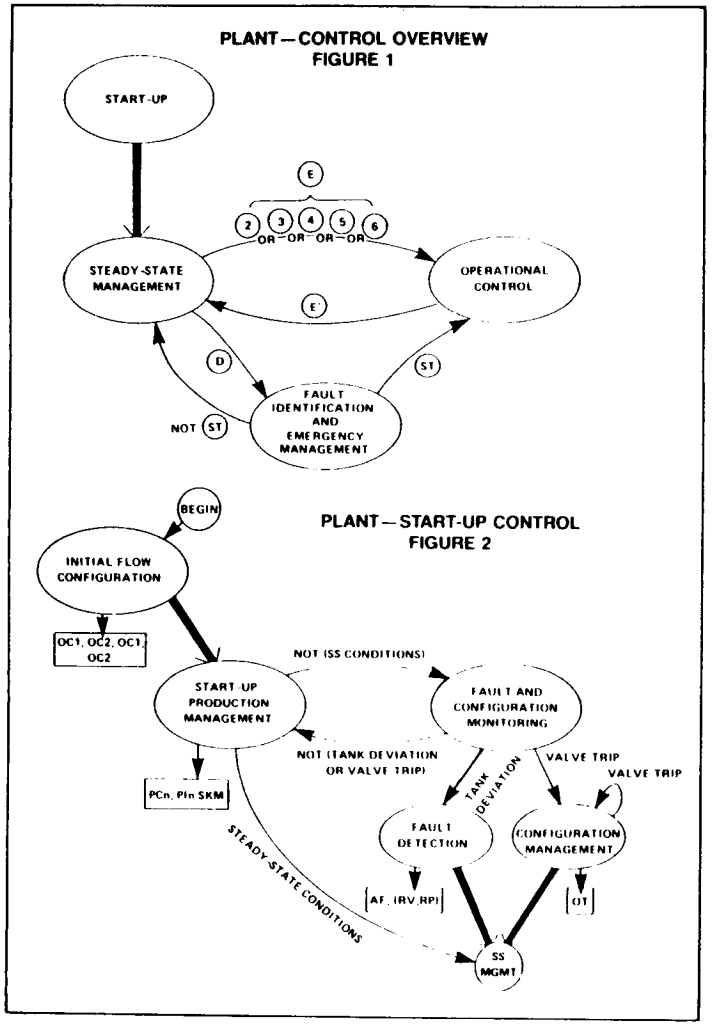
For either type of automation, models of the human operator are required which will serve as the automation "kernels". Though such models may take many forms, a near-term objective is the development of procedural models for discrete control tasks. A discrete control model represents how an operator decomposes a complex system supervision task into simpler control tasks. The model contains states and conditional transfers between states. The model describes operator knowledge representation, information flow requirements, decision making, and procedural protocols.

Such a model has been developed for a hypothetical process control system called PLANT. The model has been used to detect and classify operator errors. The success of this approach to operator modeling is currently being evaluated; it or improved versions will be used to develop requirements for and demonstrations of human error tolerant automation.

TECHNICAL CONTACT: E. A. Palmer, ARC (415) 694-6073

SPACE AUTOMATION: INTELLIGENT OPERATOR AIDS

OPERATOR TASK MODELS



OBJECTIVE

- DEVELOP OPERATOR TASK MODELS FOR USE IN INTELLIGENT AIDS FOR SPACE SYSTEM OPERATORS

APPROACH

- TASK NETWORK MODEL ENCOMPASSING: TASK DECOMPOSITION; SYSTEM KNOWLEDGE; GOALS, PLANS AND ACTIONS; INFORMATION FLOW; DECISION MAKING
- APPLY MODEL TO GENERIC PROCESS CONTROL PLANT
- MODEL THE OPERATOR OF A SPACE SHUTTLE PAYLOAD (ORS)
- MODEL A SPACE SHUTTLE GROUND CONTROLLER (INCO)

APPLICATIONS/PAYOFF

- ADAPTIVE INFORMATION DISPLAY MANAGER
- OPERATOR ERROR TOLERANT SYSTEMS
- TASK AUTOMATION KERNELS

Advanced Wide Field-of-View Stereo Displays

Because visual monitoring of remote operations will be a vital element of efficient Space Station activities, an ultra-wide field-of-view helmet mounted display was designed at Ames Research Center in 1985. This device is a major breakthrough in engineering design because it has achieved high functionality at very low weight, power, and cost. This advanced spatial display allows the user to experience visual "telepresence" since the remote scene appears to surround the wearer. Alternatively, the user may be virtually present within a completely computer-generated scene.

Currently deployed helmet mounted displays have very limited fields-of-view of approximately 30 by 40 degrees, which is very small compared with the approximately hemispherical field-of-view of human vision. Because of this restriction, excessive head movements are required to scan the scene adequately for remote manipulation and locomotion. Peripheral visual cues, which are essential to spatial orientation, are unavailable. This under-utilization of the human visual information channel seriously limits the productivity of the user. Although some laboratory systems have achieved wide horizontal fields-of-view, they have done so at the expense of binocular overlap. Further, these lab sytems have been very bulky, heavy, and fragile. Their dependence on specially built optics, miniature cathode ray tubes, and fiber optic bundles has made them too expensive to replicate.

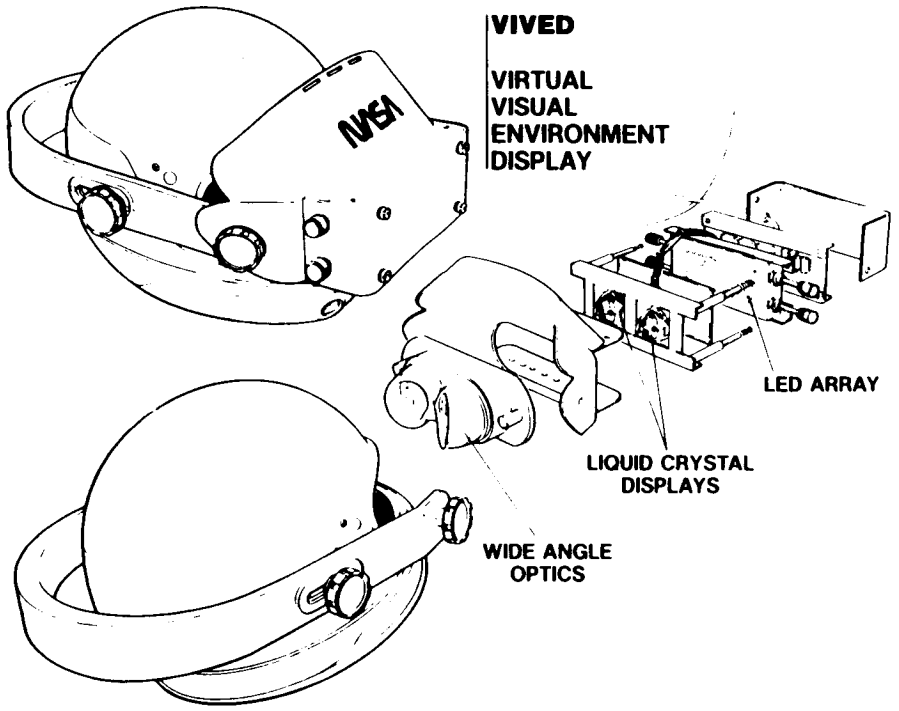
The NASA-ARC system, called the Virtual Visual Environment Display (VIVED), is being designed with a goal of minimizing system cost and complexity, while providing complete operational effectiveness. One version of the display uses simple wide angle lenses and a pair of liquid crystal displays (LCDs). It weighs less than two pounds, and is built from mass produced and inexpensive components. Since the VIVED system team has direct access to advanced LCD research products, resolution and contrast improvements will be built into the system as necessary to support operational requirements.

The ARC display provides a 120 degree total field-of-view, which provides peripheral cues, with nearly full field binocular overlap. Displayed information is slaved to head movements so that scenes viewed through the system evoke a vivid sense of actual presence within the displayed scene. For example, the user can walk around displayed objects, move in for a closer look, or look away to observe the surrounding environment. The effect can be used to enable visual telepresence for remote operations. Such a system is far more effective than hand-controlled or voice-controlled cameras for visual feedback. When combined with spatial audio cues and tactile feedback, the user can experience virtual presence in a remote or artificially generated scene.

Future plans are to evaluate and refine the system packaging and functionality, based on the results of applications studies, display technology developments, and the human factors of visual information transfer. Application to Space Station proximity operations and teleoperations tasks will be evaluated in conjunction with studies at NASA Ames Research Center and NASA's Jet Propulsion Lab. Hardware improvements will include more powerful video processing electronics, higher resolution LCDs, and use of more compact lenses.

TECHNICAL CONTACTS: Michael McGreevy, NASA-HQ (202) 453-2744
James Humphries, Informatics General Corp. (415) 694-6433
Scott Fisher, ARC (415) 694-6789

ADVANCED WIDE FIELD OF VIEW STEREO DISPLAYS



OBJECTIVE:

- LOW COST, HIGH PERFORMANCE STEREO DISPLAY SYSTEM FOR ADVANCED OPERATOR INTERFACES

APPROACH

- DEMONSTRATE SYSTEM CONCEPT FEASIBILITY USING OFF-THE-SHELF OPTICS AND DISPLAY COMPONENTS
- LEVER INDUSTRY DEVELOPMENT OF LOW COST, WEIGHT AND HIGH PERFORMANCE DISPLAY ELEMENTS
- DEVELOP OPTICS/ELECTRONICS TO COUPLE SYSTEM TO HIGH PERFORMANCE IMAGE PROCESSING SYSTEMS

PAYOFF/APPLICATIONS

- SPACE AUTONOMOUS SYSTEM OPERATOR INTERFACES
- TELEOPERATOR/TELEROBOTIC DISPLAYS
- ADVANCED SCIENTIFIC WORKBENCH

Spatial Information Display Research for Enhanced Situational Awareness and Control

The objective of the spatial display research program is to provide the technology base for productive, efficient, and safe manned space operations in complex and dynamic task environments which require spatial situational awareness and control. In particular, the research goal is to ensure effective communication of spatial information using perspective displays in advanced technology workstations.

A substantial program of experimentation is underway to quantify the functional relationships between human performance and the critical design parameters of spatial display formats. One thrust of this work is to characterize the accuracy of three-dimensional spatial judgments which are based on information derived from perspective displays. A second major emphasis is to evaluate the performance of manual control tasks using perspective displays. Studies conducted in 1985 have shown that use of spatial displays decreases reaction time and increases accuracy in tactical situational assessment, vehicle control, and remote manipulation when geometric display parameters account for the cognitive biases of the user. This program of research has benefitted from synergism with recently completed aeronautical human factors studies of perspective displays of air traffic for advanced transport cockpits.

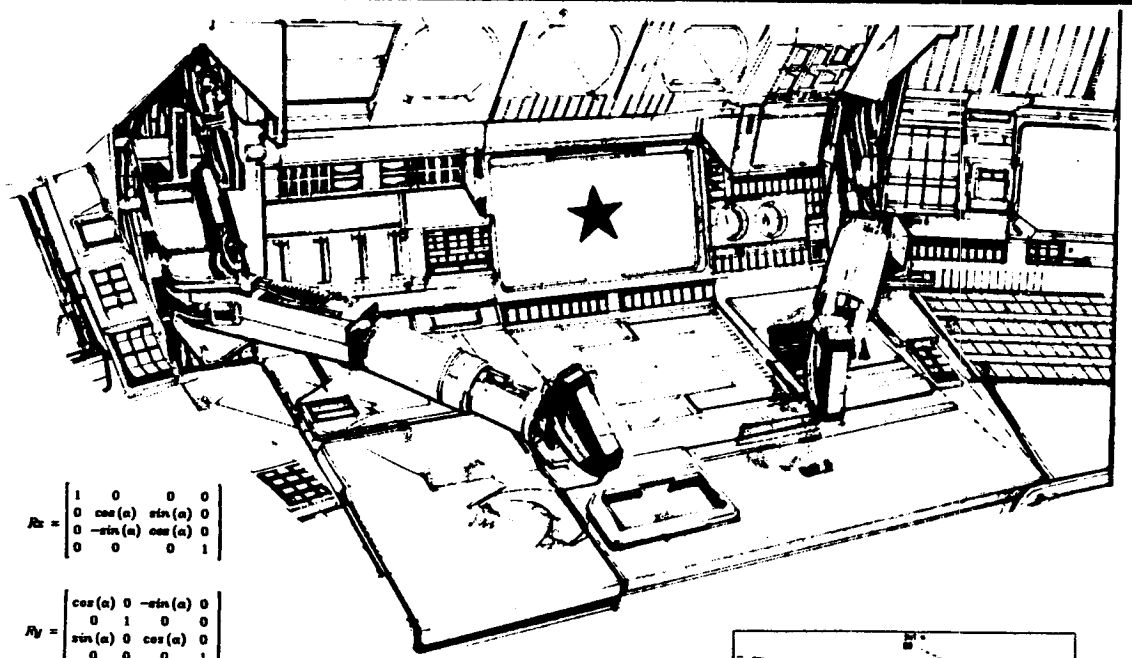
Aerospaceplane and other advanced manned spacecraft will require flight deck display design to make a quantum leap from the now familiar arrangement of small, conservatively formatted cathode ray tubes (CRTs) and electro-mechanical displays that are used in the latest transport aircraft. In order to carry out the advanced missions of these high-performance aerospace vehicles, the pilot-astronaut must be able to quickly and clearly assess flight-critical information. Advanced displays whose designs are based on information transfer research will improve the crew's capability to perform real-time situation analysis while reducing workload by presenting information in a form which is ideal for rapid and effective decision-making.

Proximity operations around the Space Station will require extensive monitoring and control by crewmembers. For space traffic control, monitoring EVA, and visual feedback in teleoperations, spatial information displays will be essential. These displays will promote situational awareness by providing a visual representation of the relationships among payloads, manipulators, orbital maneuvering vehicles, autonomous telerobots, Space Station structures, traffic control zones, and the fields-of-view of sensors and antennas. This will reduce mission costs and boost productivity by allowing simultaneous, independent activities to proceed without unexpected conflicts, collisions, damage, injury, or data loss.

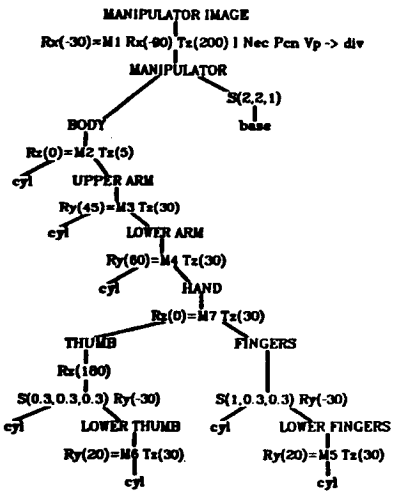
Future spatial display research will characterize sources of interpretation error, develop error-reducing format elements, and quantify optimal image geometries to ensure accurate spatial information transfer in future Space Station and aerospaceplane displays.

TECHNICAL CONTACTS: Stephen R. Ellis, ARC (415) 694-6147
Michael W. McGreevy, NASA-HQ (202) 453-2744

SPATIAL INFORMATION DISPLAY RESEARCH FOR ENHANCED SITUATIONAL AWARENESS AND CONTROL



★TELEOPERATOR MANUAL CONTROL STUDIES



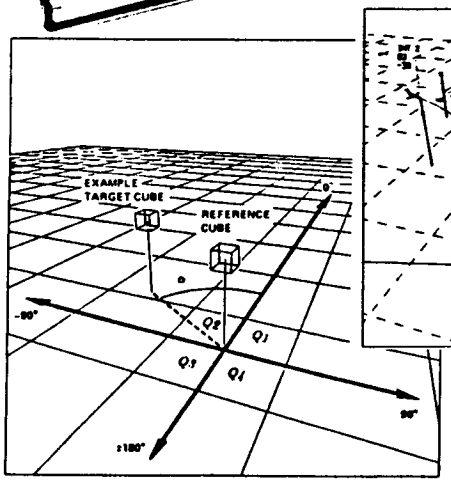
$$I=\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix} \quad Rx=\begin{bmatrix}1&0&0&0\\0&\cos(a)&\sin(a)&0\\0&-\sin(a)&\cos(a)&0\\0&0&0&1\end{bmatrix}$$

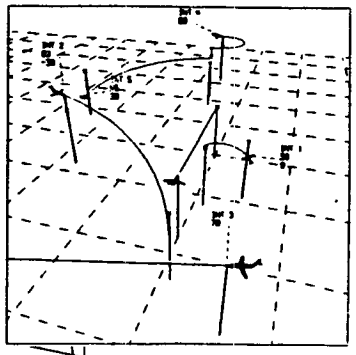
$$T=\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\tx&ty&tz&1\end{bmatrix} \quad Ry=\begin{bmatrix}\cos(a)&0&-\sin(a)&0\\0&1&0&0\\\sin(a)&0&\cos(a)&0\\0&0&0&1\end{bmatrix}$$

$$S=\begin{bmatrix}sx&0&0&0\\0&sy&0&0\\0&0&sz&0\\0&0&0&1\end{bmatrix} \quad Rz=\begin{bmatrix}\cos(a)&\sin(a)&0&0\\-\sin(a)&\cos(a)&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}$$

$$Nec=\begin{bmatrix}nx&0&0&0\\0&ny&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix} \quad Pcn=\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&a&1\\0&0&b&0\end{bmatrix} \quad Vp=\begin{bmatrix}vsx&0&0&0\\0&vsy&0&0\\0&0&1&0\\vcx&vcy&0&1\end{bmatrix}$$

★STUDIES OF INFORMATION TRANSFER VS. IMAGE GEOMETRY





★SYNERGISM WITH AERONAUTICS SPATIAL DISPLAY RESEARCH

Image Management for Space Operations

Several characteristics of future space systems will require that fundamental improvements in information technology be made. First, increasing system complexity and the costs associated with current operating approaches will require that fewer operators, whether on ground or in space, will monitor, supervise, and control increasingly complex systems. Second, because humans seem to process information best (fastest and most error free) when it is presented graphically or in the form of pictures rather than alphanumerics, new information systems will be image-based rather than symbol-based.

Ways to make the image storage and transmission process more efficient are being developed. Image management technology will be used to acquire and review earth and space (astronomical) imagery, to implement image-based documentation and repair systems, medical image data bases, and image systems that assist scientists, engineers, or production personnel to quickly understand and interpret complex phenomena.

In addition to the efficient representation of images, other tools will be required to manipulate images. Such tools will be used to reduce or enlarge images, move them from one area of a screen to another, and, in some cases, to alter the properties of the image (e.g., through the use and manipulation of color, spatial properties, or operator viewpoint). For image management systems where the final user is a human rather than a machine, such image representation systems and manipulation tools should be matched to the characteristics of the human visual systems. For example, it is pointless to provide image resolution beyond that achievable by the human.

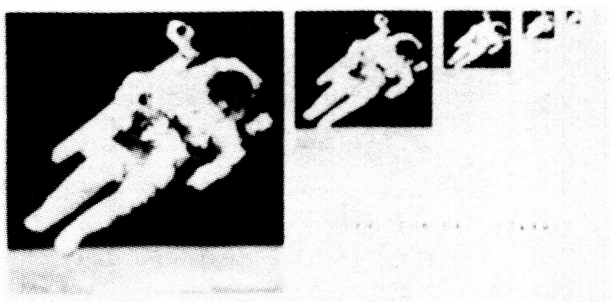
Efficient image codes have been developed that code each image in a manner that is optimal both with respect to information theory and from the point of view of the viewer. For example, one such code is the resolution pyramid, which divides an image into differing resolution bands, rather than arbitrary spatial parts such as pixels. The resolution pyramid code developed at ARC is theoretically ideal (in the sense of minimum information loss). Its utility and human matching characteristics have been experimentally demonstrated for progressive image transmission (where a reduced size low resolution image which requires very few bits to encode is transmitted and viewed preliminary to the entire image) and in image zooming (a rapid change of scale with correctly managed resolution). In summary, proper image codes will not only reduce image storage and transmission requirements, they will result in imagery that is appropriately matched to the human viewer.

A next step will be to develop image management systems, based on these efficient codes, for selected applications in the space environment. For example, an image management system which encompasses major automated Space Station systems (life support, data management, orbital maintenance, etc.) will enable the safe and effective supervision and diagnosis of such systems with a minimum number of dedicated human operators. The development of such systems is technically demanding and will require the best efforts of vision scientists and information technologists.

TECHNICAL CONTACT: A. B. Watson, ARC (415) 694-6290

IMAGE MANAGEMENT TECHNOLOGY

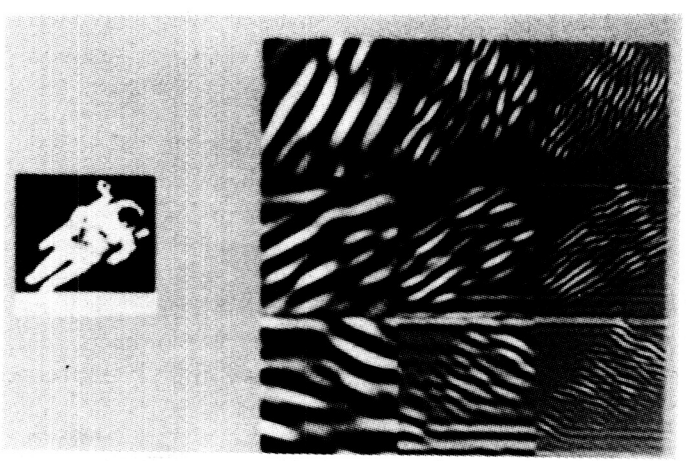
TECHNOLOGY FOR IMAGE: CODING • STORAGE • DISPLAY • TRANSMISSION • SEARCH
BASED ON: IMAGE PROCESSING • HUMAN VISION



IDEAL PYRAMID

IMAGE DATABASE

VARIABLE RESOLUTION



CORTEX TRANSFORM

Models of Color Constancy and Color Perception

Until recently the human ability to correct for changes in the ambient light has been better than the ability of computer visions systems. ARC has designed a new algorithm which, under noise-free circumstances, outperforms the human visual system. The algorithm has been implemented on a UNIX 4.2BSD machine using the C-programming language.

The images on the left side of the opposite figure show the same set of objects photographed under two different ambient lighting conditions. The camera images are quite different because of the difference in the ambient light. The particular lights used in this demonstration were chosen to appear identical to the human eye, although they are physically different. (The ambient lights are metameric.)

Variations in the color of the ambient light occur frequently. As we pass from early morning sun to high noon, from cloudy days to sunny days, from natural light to artificial light, the color of the ambient lighting changes significantly. Film images record such changes, but we do not perceive large changes. Instead, the visual system performs an automatic correction, a neural adjustment that compensates for the change in the color of the ambient light. The middle picture shows an apparatus which measures the human ability to adjust for changing ambient light conditions. As anyone who has tried to find his car in a parking log illuminated by inexpensive sodium vapor lights knows, the ability to correct for changes in the ambient light is limited. In order to model human performance, it must first be measured.

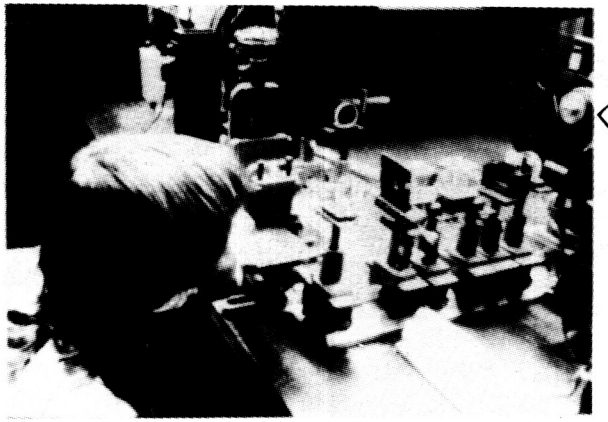
The optimal algorithm has applications to several areas beyond human vision. First, the ability to accurately recognize surface reflectance independent of the ambient light should be helpful in processing remote sensing data in land survey research. Second, the ability to estimate surface reflectance is a useful tool in the development of machine vision algorithms for inspection of parts. Ways of reducing the algorithm's performance to bring it into line with human performance are presently being studied, and plans are being made to use the adjusted version of the algorithm as a tool for predicting color appearance during the design phase of instrumentation displays.

TECHNICAL CONTACT: A. B. Watson, ARC (415) 694-6290

MODELS OF COLOR CONSTANCY AND COLOR PERCEPTION

FAILURES OF COLOR CONSTANCY

- SAME OBJECTS, DIFFERENT ILLUMINANTS
- CAMERAS, SENSORS RECORD SURFACE COLORS AS DIFFERENT
- HUMANS CORRECT FOR COLOR DIFFERENCES OVER BROAD RANGE OF CONDITIONS



- COLOR PERCEPTION EXPERIMENTS

• ACCOMPLISHMENTS

- NEW MEASURES OF HUMAN COLOR SENSITIVITY
- COMPUTATIONAL MODELS FOR COLOR APPEARANCE
- ALGORITHMS FOR MACHINE COLOR CORRECTION

• APPLICATIONS

- USAGE STANDARDS FOR COLOR CODING IN DISPLAYS
- COLOR CORRECTION FOR REMOTE SENSING
- COLOR-BASED OBJECT RECOGNITION FOR MACHINE VISION SYSTEMS

Mockup Development for Space Station Proximity Operations

One of the most important functions of the Space Station will be to serve as a base for orbital operations. These include satellite retrieval, repair, refueling, and deployment, as well as servicing of externally mounted Space Station payloads. To support these tasks, a variety of vehicles will operate in close proximity to the Space Station, including: orbital transfer vehicles (OTVs) for intermediate and geosynchronous orbital operations, orbital maneuvering vehicles (OMVs) for low earth orbit operations, manned maneuvering units (MMUs) for close-in activities, and Space Shuttle Orbiters.

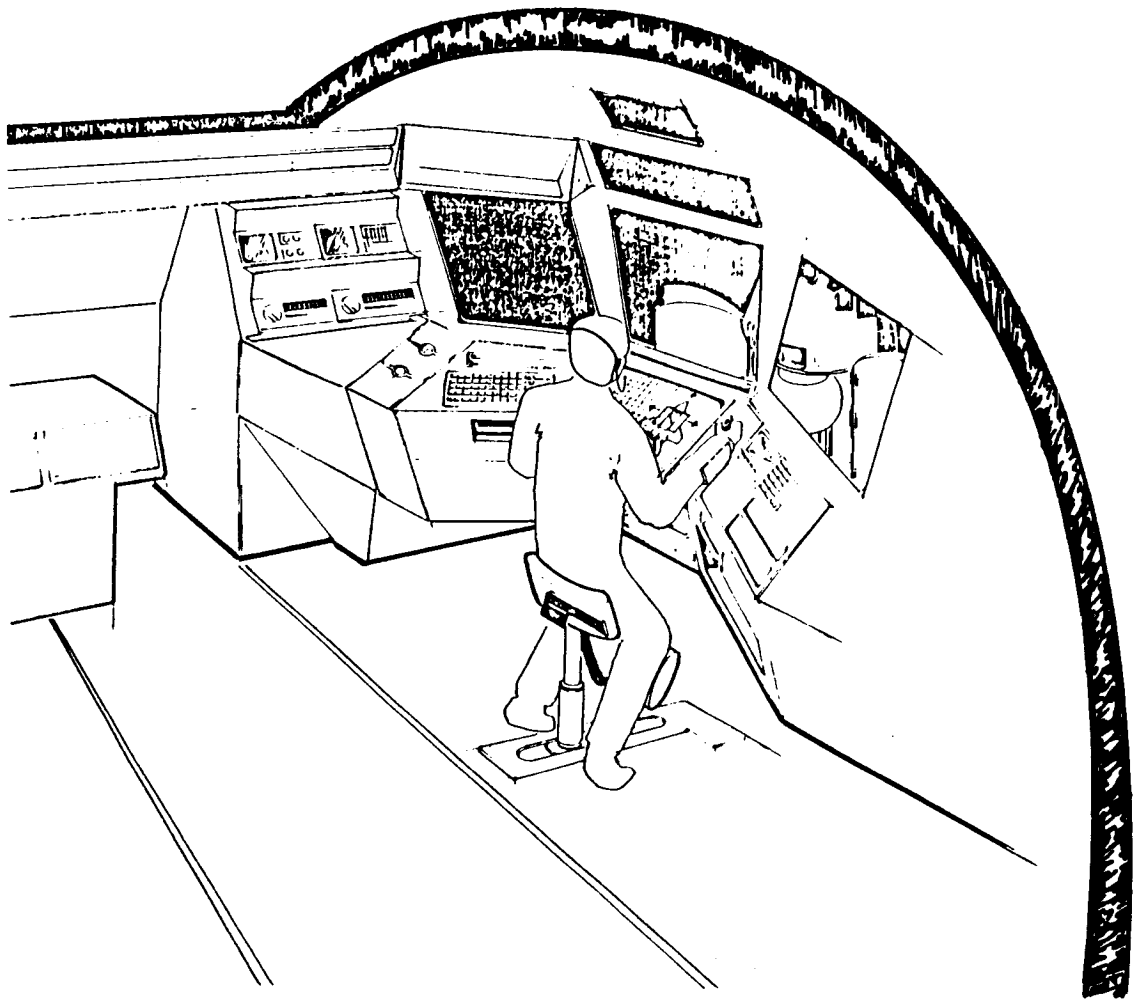
For productive, efficient and safe operations in this complex task environment, it is essential that the human interface to these systems is well designed. While automation will take over some tasks and help with others, the human operator will exert supervisory control, orchestrating the activities of highly-automated vehicles and systems to conduct proximity operations.

To support focused research which addresses the human/automation interface issues of proximity operations, a mockup of a PROX OPS workstation is being built at Ames Research Center. The idea is to bring together very advanced research concepts in working demonstrations and to obtain user evaluations and suggestions early in the research and development process. This rapid prototyping strategy is intended to improve the transfer of research products to operational readiness so that the agency's human productivity goals are achieved.

The advanced research concepts to be integrated into the mockup include expert system interfaces for fault diagnosis of the orbital refueling system; innovative display formats for space traffic control, EVA monitoring, and teleoperations; voice communication with automated systems to bypass cumbersome keyboard use; and multi-media knowledge base interactions. Mission-oriented proximity operations scenarios will be used to guide the evaluation of a variety of workstation configurations.

TECHNICAL CONTACT: Dick Haines, ARC (415) 694-5719
Leon Harrison, ARC (415) 694-6938

MOCKUP DEVELOPMENT FOR SPACE STATION PROXIMITY OPERATIONS



OBJECTIVE

- INTEGRATED OPERATOR INTERFACE TECHNOLOGY FOR SPACE PROXIMITY OPERATIONS
- RECONFIGURABLE MOCK-UP TO SUPPORT TECHNOLOGY EVALUATIONS

ELEMENTS

- ELLIPTICAL ENDCAP
- PERSPECTIVE SPATIAL DISPLAYS
- VOICE 1/0 TECHNOLOGY
- MULTI-DOF CONTROLS
- COMPUTER GENERATED OUT-THE WINDOW VIEWING

SCHEDULE

- OPERATIONAL IN FY86

Crew Station Human Factors

Advances in display, control, and user/computer interaction (UCI) technologies have been rapid, and several of these advanced technologies have been incorporated into aircraft cockpits. These technologies, such as voice recognition and synthesis, high-resolution color graphics, and multifunctional displays and controls, have been used to reduce operator workload, enhance information transfer between operator and computer systems, and support the crewmember in several roles. These rapid advances, however, have left gaps in our understanding of the way in which these technologies may be used to enhance operator performance, specifically within the space environment.

The purpose of this program is to examine advanced display, control and UCI technologies and to determine where and how they may be incorporated into space crew workstations which support the operator in the on-orbit conduct of crew activities (see opposite figure). A matrix was created to identify issues derived from the interaction between advanced technologies and user information needs. A research plan was then developed from these issues, and is presently being implemented. Typical UCI issues being examined are: graphics for rendezvous and proximity operations, highlighting within display formats, six degree-of-freedom manual control, use of multifunctional displays and controls, and windowing for user/computer dialog.

A Human Factors Laboratory (HFL) was established to provide a test environment for this program. Experiments are being conducted to examine specific issues, and findings are being incorporated into a workstation designed to simulate on-orbit operations in essential aspects. Several on-orbit operations scenarios are presently being developed to support HFL evaluations of display, control, and user/computer dialog concepts, with Astronaut Office, Operations and Engineering personnel participating in these evaluations. Products of this program are guidelines for the incorporation of advanced technologies into space crew workstations, and demonstrations of their use in simulated on-orbit operations scenarios.

TECHNICAL CONTACT: Marianne Rudisill, JSC, (713) 483-4065

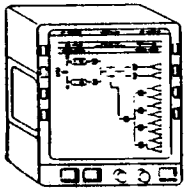
CREW STATION HUMAN FACTORS

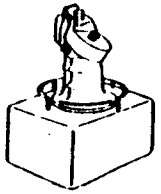
ADVANCED DISPLAY,

CONTROL,

& USER/COMPUTER INTERACTION

TECHNOLOGIES



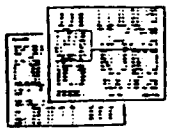


SPACE-RELATED RESEARCH ISSUES

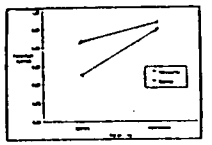
- DISPLAY FORMAT OPTIMIZATION
- ELECTRONIC CHECKLIST
- MULTIFUNCTION CONTROLS AND DISPLAYS
- 6 DEGREE OF FREEDOM HANDCONTROLLER

HUMAN FACTORS EXPERIMENTS AND EVALUATIONS

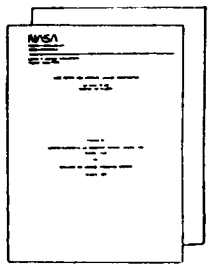
DISPLAY FORMAT OPTIMIZATION



USER PERFORMANCE DATA



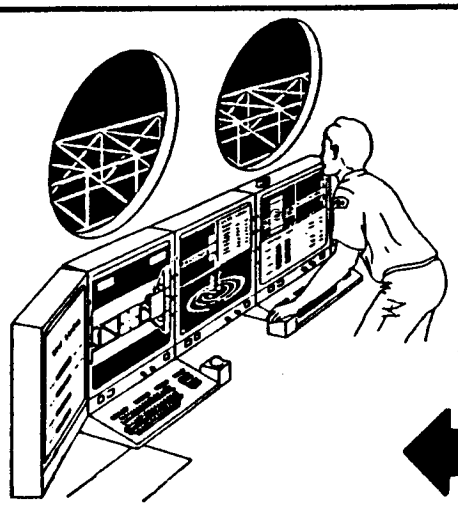
RESULTS/GUIDELINES



SPACE-RELATED

WORKSTATION

APPLICATIONS



Study of Cursor Control Devices in Zero-G

One of the problems often encountered in the development and testing of workload measures is that the tasks used in the experimental evaluations have not themselves been calibrated. To this end, a battery of tasks ranging from relatively simple laboratory tasks to complex, multi-task simulations have been developed and calibrated. The software for these tasks has been given to many of the contractors and grantees who participate in the program as well as to members of other organizations. The data from several of these tasks have been used as a data base for different workload modeling efforts, as well. This has provided a common focal point for otherwise diverse efforts.

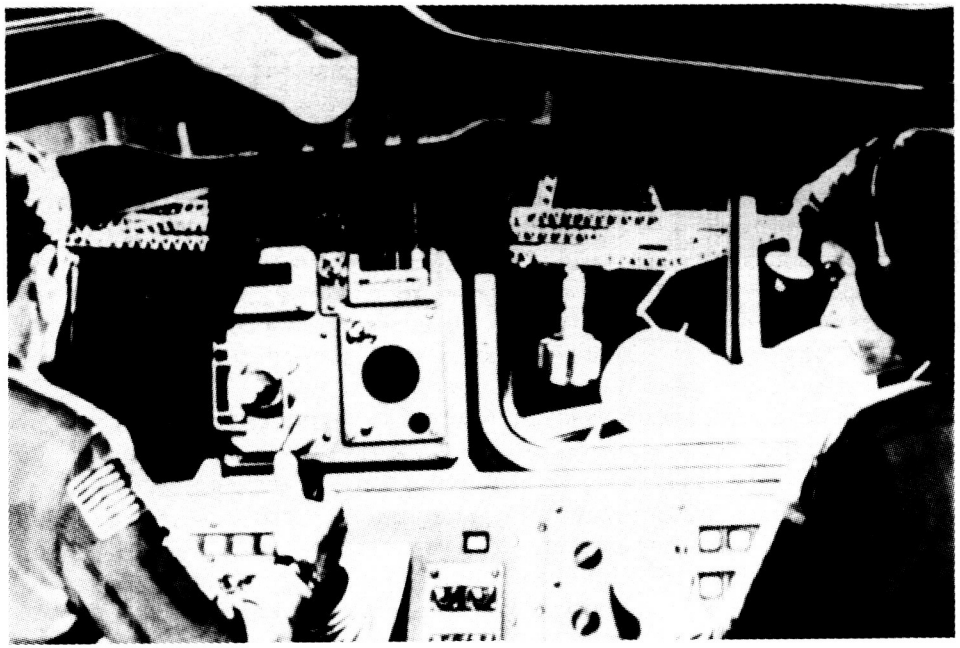
One example of such a task is the "POPCORN" supervisory control simulation. This task was designed to provide a wide range of time-related stressors on operators by modifying subtask schedules, window of opportunity for performance, dependencies among tasks, and penalties for procrastination. An example of one application in which this task was used is a joint study undertaken with SRI. The goal of this study was to find experimental evidence for the hypothesized relationship between the type A and type B personality characteristics and differences in subjective, behavioral, and physiological responsiveness to task imposed stressors. The results of this study provided striking evidence that type A individuals respond quite differently than type B individuals; they underrate the quality of their own performance and the effort they exert, take less advantage of opportunities to minimize the effects of over-load situations, and react (subjectively and physiologically) significantly more to challenging tasks. The most significant finding was that type A subjects, but not type B subjects, evidenced significant elevations in systolic and diastolic blood pressure in response to elevated task demands, although the two subject-populations each had normal resting blood pressure. The evidence from this study has important implications in understanding the correlation found between type A personality and the development of cardiovascular disease.

An example of how criterion tasks developed at ARC has been used in solving operational problems may be found in an experiment to be conducted during a shuttle flight in the fall of 1986. The goal of the experiment, to be conducted in collaboration with MIT, is to compare three cursor control devices in zero-G. The devices under consideration are: a track ball, arrow keys, and a joy stick. The task proposed by ARC requires astronauts to make a series of ballistic target acquisitions (moving a cursor from one position on a CRT to another) based on a decision about the similarity of currently displayed information to remembered values. The difficulty of the decision and target acquisition tasks will be varied according to well-known psychological principles. Data will be obtained from astronauts early, middle, and late in the flight to ascertain the role of accommodation to the zero-G environment in controlling the movement of a cursor with different devices.

TECHNICAL CONTACT: S. G. Hart, ARC (415) 694-6072

NASA-AMES WORKLOAD AND PERFORMANCE RESEARCH

STUDY OF CURSOR CONTROL DEVICES IN ZERO-G



OBJECTIVE

- EVALUATE 3 CURSOR CONTROL DEVICES EARLY AND LATE IN ZERO-G EXPOSURE DURING FY86 SHUTTLE MISSION

APPROACH

- ARC/UNIVERSITY COLLABORATION
- ARC-DEVELOPED "FITTSBERG" TASK AS CRITERION TASK
- COMPARISON OF VERTICAL, HORIZONTAL, AND ANGULAR MOVEMENTS TO ACQUIRE TARGETS WITH:
  - TRACK BALL
  - JOYSTICK
  - ARROW KEYS

Workload Prediction: Remote Manipulation Arm Application

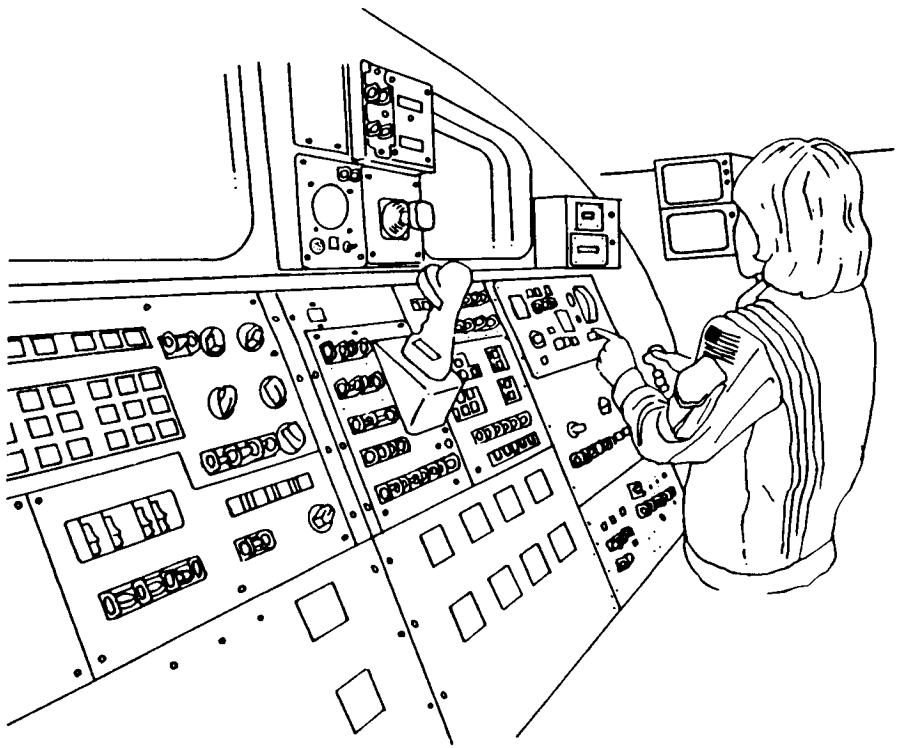
Optimum human performance is generally obtained when levels of workload - both physical and mental - are optimal. Physical workload measurement is a well established technology that has been exploited for many years by industrial engineers to design workplaces which maximize worker productivity. As the systems of the workplace become more heavily automated, however, physical workload is less and less a problem because automation provides the physical means of achieving task objectives. Often, physical workload is replaced by mental workload; the operator must mentally keep track of the automation, must program the automation to achieve desired performance, and must monitor and determine whether the automated system is performing properly. Just as in the case of physical workload, too much mental workload can lead to performance breakdown; too little workload to operator boredom, complacency, and a high rate of operator error.

A comprehensive workload assessment and prediction methodology has been developed. Initially intended for aeronautical applications and tasks, its use is being modified for use in the design and operation of space systems. Although the workload technology is relatively advanced, little is known about how the special conditions of space (e.g., micro-gravity) will affect operator workload, whether physical or mental.

An effort to develop and validate a space workload prediction and assessment tool has been initiated which exploits the ability to perform space research aboard NASA's Shuttle. The first application of the space workload methodology has been to model (predict) operator workload associated with performance of various tasks using the Shuttle's Remote Manipulator System (RMS). The next step will be to ground test model predictions at the Johnson Space Center's RMS simulator. Following successful evaluation on the ground, a space experiment will be conducted to provide a final validation of the usefulness of the model and methods in the space environment. A secondary goal of this research is to compare the workload of different RMS camera-control methods (e.g., manual vs. voice).

TECHNICAL CONTACT: S. G. Hart, ARC (415) 694-6072

WORKLOAD PREDICTION FOR SHUTTLE RMS OPERATIONS



OBJECTIVE

- PREDICTION OF WORKLOAD ASSOCIATED WITH OPERATOR CONTROL OF REMOTE MANIPULATOR ARM
- ASSESSMENT OF ACTUAL WORKLOAD UNDER IG SIMULATED OPERATION

APPROACH

- COLLABORATIVE ARC/JSC ACTIVITY
- FORMAL TASK DESCRIPTION
- ANALYTIC TASK REPRESENTATION USING AMES MODEL
- PART TASK TEST OF MODEL AT ARC
- SIMULATOR VALIDATION IN RMA SIMULATOR AT JSC

PAYOFF

- GROUND VALIDATED WORKLOAD PREDICTION AND ASSESSMENT FOR RMA TASKS
- COMPARATIVE, QUANTITATIVE ANALYSES OF NEW RMA OPERATOR INTERFACE TECHNOLOGY (e.g. VOICE)

Computer Models of Position, Motion, and Strength of Human Operators

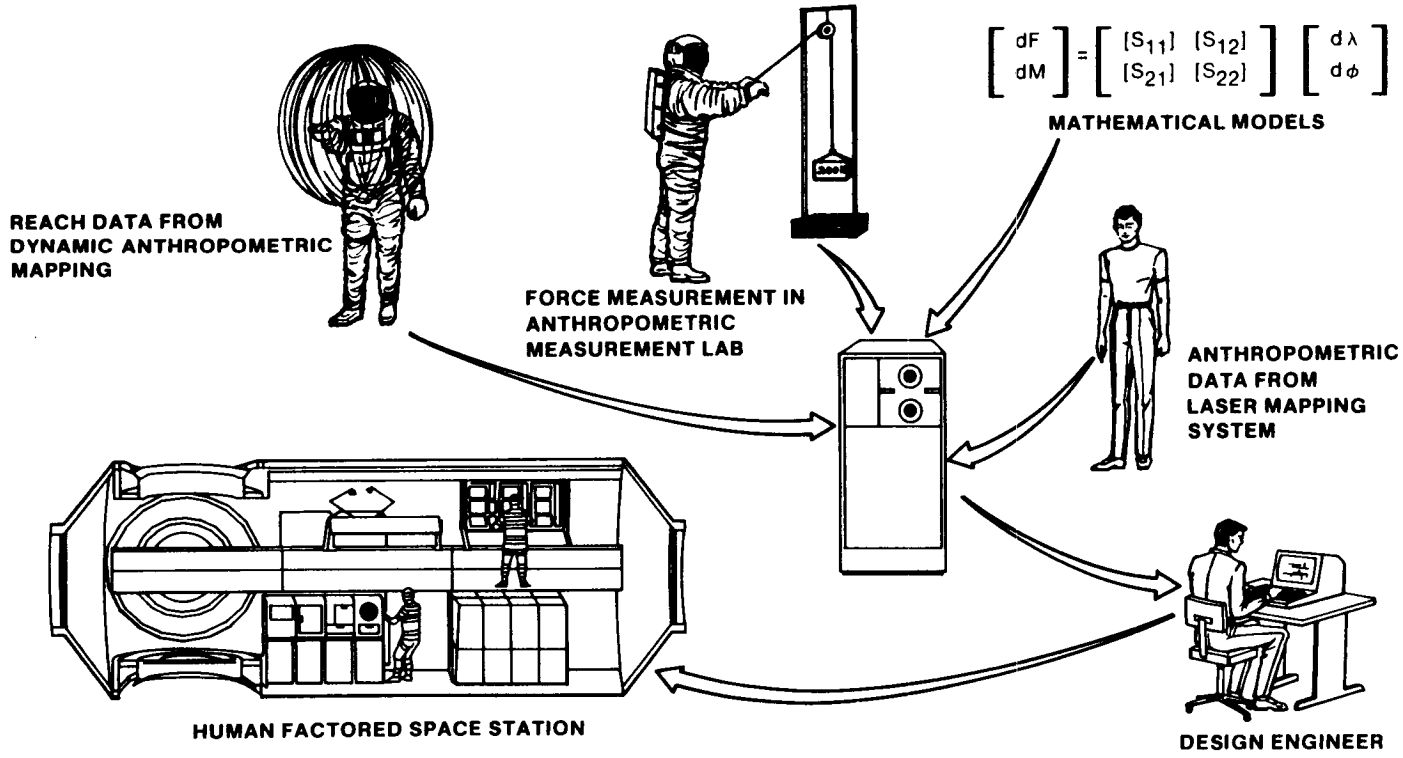
Computer models of human beings can be used to bring human factors to the forefront of workspace design efforts. This program has been designed to develop modeling techniques for human strength and motion. A modeled figure can be placed in a workstation such as the Shuttle middeck or the proposed Space Station modules, where the man-machine fit can be evaluated. The computer model, TEMPUS, positions the body in various poses automatically or with user inputs. For example, the figure can be commanded to reach a certain point in space with its left or right hand or foot, and will automatically assume a reasonable position for making this reach. The user may specify any joint angles by typing in the specific joint values or by positioning the setting of a potentiometer on the screen. The reachability of any point may be calculated by an automatic reach generation algorithm, described in "A Geometric Investigation of Reach", a doctoral dissertation by James Korein (1984). Alternatively, reach envelopes may be collected from real people and graphically presented in the workstation.

The first steps toward modeling human strength in this system have been taken. A review of the literature has been performed which describes the state-of-the-art in modeling human force from a muscular starting point. The alternative of modeling the body with a rotary motor at each joint is also being investigated. Data on single joint strength in zero gravity as a function of position and restraint type will be collected on the KC-135 during the coming year.

Data for the anthropometric data base will be collected automatically during the coming year with the laser-based Anthropometric Mapping System. The software to calculate the coordinates of points on the surface of the human body has been developed and tested; work is underway to join multiple images to generate a total volume (front, back, and sides). Additional data for the strength model will be extracted from films of extravehicular activity (EVA). In particular, the operations performed in large structure assembly will be studied, and the biomechanics of the performance will be compared with that observed in the neutral buoyancy simulators.

TECHNICAL CONTACT: Barbara Woolford, JSC (713) 483-4065

COMPUTER MODELS OF POSITION, MOTION AND STRENGTH OF HUMAN OPERATORS



Space Station Operational Simulation

The Space Station operational simulation (OpSim) is envisioned as a computer model that simulates the actions of the Space Station crew to help understand and resolve human productivity, automation, and interior layout issues. OpSim is expected to be a useful tool for examining the implications of Space Station configuration, payload complement, crew mix, and required level of automation. It will employ graphics, simulation, and a data base representing the relevant portions of the Space Station and related vehicles to accomplish this goal. OpSim will examine layouts, configurations, and crew complement in terms of location and productivity as measured by time. Typical questions that might be addressed include: what is the best equipment layout for a module; how many crew members are needed for a given Space Station configuration, automation level, and payload complement; what is the optimum connection strategy for modules; what is the optimum location for safe havens; what is the predicted distribution of crew location in a particular scenario; and how long do complicated tasks take to accomplish?

A description of the crew's operating environment will be entered interactively or from Space Station data bases, the actions of the crew simulated, and results presented on a raster graphics CRT. The OpSim data base will include a number of vehicles (Space Station Shuttle, Hermes, etc.), missions, and crews for each vehicle. Vehicles will consist of modules filled with equipment (subsystems, payloads, tools, parts, etc.). Equipment failure and repair will be modeled as a function of equipment usage. Tasks will be scheduled to simulate crew activities. Wherever possible, data will be taken from relevant Space Station data bases, mock-ups, and space flight experience. The simulation will be accomplished by assigning tasks to crew members by priority. The variable modeled will be time to accomplish tasks and move about the Space Station. Crew and equipment location will be tracked, and provisions for simulated crew members to cooperate on tasks will be made. Output will consist of a timeline that can be manipulated to generate summaries of crew and equipment usage and slack times, movement tracks, job status, and histograms of crew location. Most output data will be in spread sheet format for further manipulation and display.

The OpSim user interface uses commercial application software available on the Apple MacIntosh. "Filevision" is used for data input and "JAZZ" for output manipulation and display. Each of these packages has been customized to reduce user training and startup time to a minimum. In addition, the hardware and software required by OpSim is useful for a variety of tasks other than Space Station simulation. OpSim will be validated by simulating SpaceLab 3 operations and comparing simulated versus actual results. SpaceLab 3 was chosen for model validation since a wide variety of diverse activities was required and the data are readily available. Finally, OpSim will be used in a Life Science Module automation study to determine which aspects of non-human life science research and servicing consume the most crew time. OpSim has also been identified as a potentially significant contributor in resolving several issues identified in the Human Productivity study lead by Lockheed.

TECHNICAL CONTACT: Yvonne Clearwater, ARC (415) 694-5937

SPACE STATION OPERATIONAL SIMULATION
(OpSim)

SPACE STATION AND PAYLOAD:

- HARDWARE CONFIGURATION
- STAFFING
- CREW TASKS

SPACELAB 3 DATA

MODEL VALIDATION

OpSim

- MAINTAIN CONFIGURATION AND OPERATIONS DATA BASE
- SIMULATE THE IMPLICATIONS OF THE DATA BASE
- PRESENT SIMULATION RESULTS

- PRODUCTIVITY MEASURES
- CREW, EQUIPMENT, AND JOB TIMELINES
- CREW AND EQUIPMENT LOCATION OVER TIME

CONFIGURATION AND OPERATIONAL CONCEPTS

MOCKUP STUDIES

FLIGHT

Factors Affecting Space Station Crew Performance

The U.S. Space Station will be a highly structured, small-group environment, where sustained productivity and safety over long periods of time in isolation will be dependent upon a number of sociopsychological, personality, task, and environmental variables. There is little question that individual station crewmembers will be highly technically qualified for their roles in station operations. As a result of years of research, a substantial amount is known about the reactions of individual humans to spaceflight, and training these individuals to perform their technical responsibilities at high levels of competence has been successful. However, recent research in various group performance situations (most notably aviation) has demonstrated that a collection of technically competent, stable, healthy individuals does not guarantee effective team performance. Regardless, little research exists to guide selection efforts, training, and management aimed at the facilitation of new performance in environments like the Space Station.

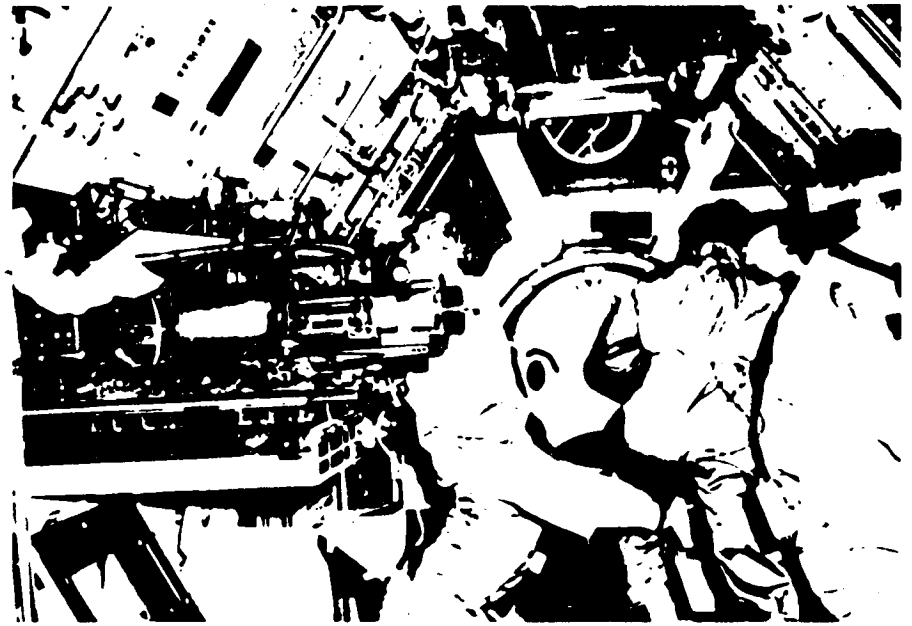
Previously, factors such as the novelty of spaceflight, the relatively short duration for most flights, and the fact that crews have trained together extensively before flight have mitigated against group performance difficulties. In other environments containing many of the essential ingredients of Space Station operations, there have been substantial operational problems related to group dysfunction. These incidents (including extreme depression, total work stoppage, and violence) have been reported in the Soviet space program, Antarctic research stations, strategic nuclear submarines, and other isolated environments. Even minor manifestations (e.g., personality conflicts, inadequate group structure, lack of cohesiveness, etc.) can cause deleterious effects on productivity. Multipilot aviation accident statistics are replete with tragedies caused by ineffective crew coordination, even though most of the individual crewmembers involved had long histories of successful performance and technical competence.

Group factors have traditionally received very little attention because of the inconsistencies in the literature and methodological difficulties associated with the vast complexities of human interaction. High speed computers and sophisticated analytical techniques have solved many of these problems, but most laboratory studies are overly sterilized and not readily generalizable to the Space Station environment.

The purpose of this research program is to provide such guidance. Although there are myriad factors affecting the group performance process, they can be roughly sorted into three large classes—input, process, and output variables, and these are portrayed in the accompanying figure. Input variables refer to the personal characteristics individuals bring into the group, the characteristics of the group itself, and factors related to the environment or the task performance situation in which the group is functioning. Process variables refer to the dynamics of group interaction or how group members communicate with each other in order to coordinate their individual actions. Output variables are those related to how well the group performed the task, but also other important outcomes indicating how group members feel about each other and what they have learned as a result of the interaction. All of these factors are interrelated in complex ways and are important predictors of the group performance process.

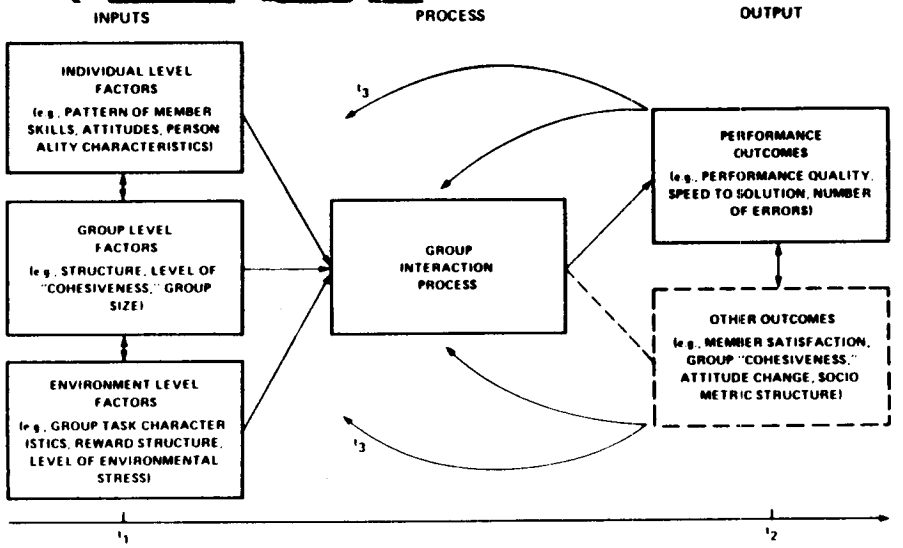
TECHNICAL CONTACT: H. C. Foushee, ARC (415) 694-6114

FACTORS AFFECTING SPACE STATION CREW PERFORMANCE



NEW MISSION CHARACTERISTICS

- LONGER DURATION
- CREW HETEROGENEITY
- ROUTINIZED MISSIONS
- LESS TRAINING
- NEED FOR HIGH PRODUCTIVITY
- GREATER USE OF AUTOMATION & ROBOTICS



Advanced Space Suit Technology

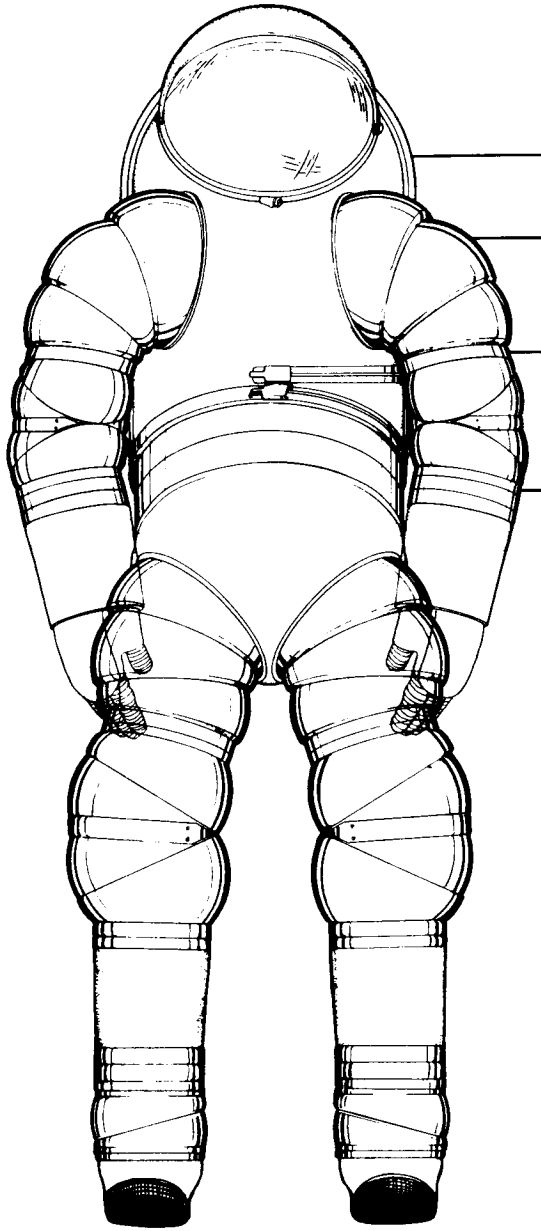
EVA has been identified as a major element of Space Station operations. Historically, the role of EVA has been one of extreme conservatism, in that EVA was (and is) either planned as a short duration activity or used for contingency operations of minimal duration. The EVA hardware was subsequently designed to meet these requirements, but with the luxury of ample time between missions for refurbishment, resizing, and routine maintenance.

The current baseline (STS) EVA system will not meet the requirements of routine Space Station EVA operations. Due to the extensive number of EVA hours being projected for Space Station, issues that have not been of concern in the past will become drivers in the selection and development of technologies required to meet routine Space Station EVA requirements.

The Ames Research Center has an ongoing development program to address EVA suit technology issues for Space Station. The program emphasis is being placed on technology areas that provide: no prebreathing requirement; improved suit and glove performance; increased hardware and system life; hazard protection (radiation, mechanical); minimal maintenance; quick change sizing capability; and reduced manufacturing and operations costs. These technologies will be demonstrated, tested, and evaluated in a fully functional space suit configuration (ARC AX-5 Hard Space Suit Demonstrator, shown opposite). This suit is being designed to operate at one atmosphere internal pressure. Completion of two suits is projected for November, 1985.

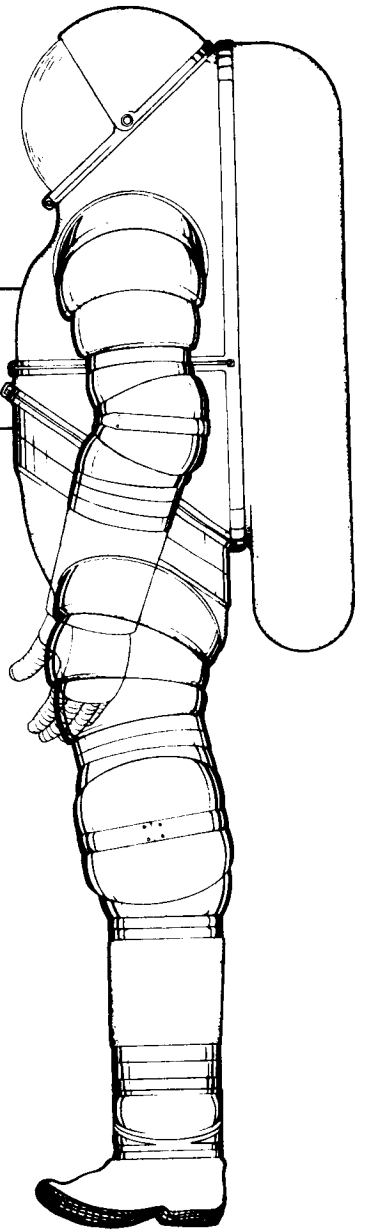
TECHNICAL CONTACT: H. Vykukal, ARC (415) 694-5386

AMES AX-5 HARD SPACE SUIT



DESIGN FEATURES

- REAR ENTRY CLOSURE
- MULTIPLE BEARING JOINTS
- UNIVERSAL FIT TORSO
- LOW TORQUE SEALED BEARINGS
- TORSO LENGTH SIZING RINGS
- EXTREMITY SIZING RINGS
- MULTIPLE WALL METAL STRUCTURE



OPERATIONAL FEATURES

- ONE ATMOSPHERE PRESSURE
- HAZARD PROTECTIVE STRUCTURE
- ON ORBIT SIZING
- MINIMAL MAINTENANCE
- MINIMAL PARTS INVENTORY
- WETF QUALIFIED

Advanced Space Glove Technology

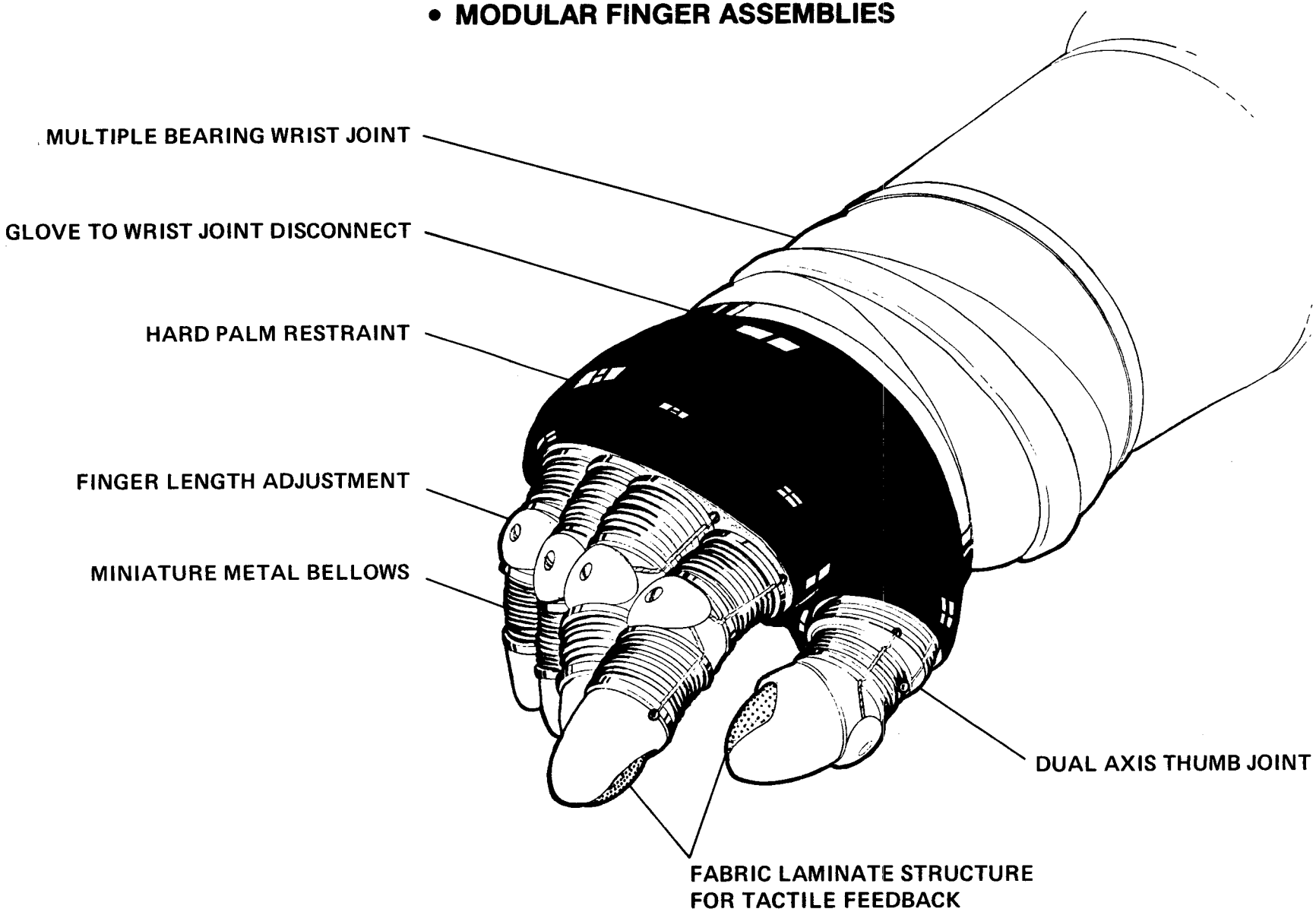
Projected requirements for extravehicular activity on Space Station are for considerable increases in both frequency and duration over previous space missions. Such increases will require increased durability, maintainability, and hazard protection; zero-prebreathe capability is also required to effect frequent and rapid egress and ingress without danger of bends. The latter capability will require a smaller internal pressure differential between the suit and Space Station than has previously existed between suit and habitat. The more generally acceptable solution to "equating" the two internal pressures, technology state-of-the-art permitting, is to develop a high pressure suit. Currently, the limiting factor is glove technology. Although other high-pressure suit components have been demonstrated, a totally suitable high-pressure glove that meets all of the previously noted requirements and provides ease of flexibility and tactile sensitivity does not now exist.

As part of its hard, high pressure suit demonstrator development program, ARC is developing a hard, high pressure glove. Based on principles similar to those used in developing the suit itself, the glove should provide the same maintenance and protection advantages as the suit. In addition, to insure reliability, the use of manufacturing techniques proven in other technology areas is being explored. The hard glove demonstrator will be tested early in 1986.

TECHNICAL CONTACT: H. Vykukal, ARC (415) 694-5386

AX-5 HARD GLOVE

- ONE ATMOSPHERE PRESSURE
- MODULAR FINGER ASSEMBLIES



Extra Vehicular Activity (EVA) Performance Aids

Development activities in EVA performance aids at JSC have focused around Space Station servicing tasks. Concepts for a helmet mounted display, a powered glove end effector and a generic work station for EVA crewmen were examined during FY85.

Helmet Mounted Display - The helmet mounted display is a concept that allows several types of EMU information to be displayed in a convenient manner. Life support instrumentation, computer detected cautions and warning including corrective actions, and tutorial instruction which might include schematics and text information on maintenance and repair items can all be included. Several design concepts have been investigated, and at this time, the CRT appears to be the best choice for video information needed in this concept. Other display technologies such as electroluminescence, plasma, light emitting diodes, and liquid crystal displays will be reevaluated as their technological display capabilities increase.

The most significant result of this project is the indication that a reasonably compact, lower power, virtual image system can be built. Since the feasibility unit has not yet been built, human factors information such as ease of use, distraction from main work task, visibility in high lighting conditions, and display duty cycle as well as overhead reliability still remain as major questions.

Power Assisted Glove End Effector - The purpose of this device is to create a power tool system to facilitate the construction, assembly and servicing tasks of the Space Station during EVA activities. When using a pressure suit, the use of hand tools can be tiring due to excessive hand fatigue. The main thrust of this program is to study the man/tool interface problem and provide at least one solution to minimize hand fatigue.

The present concept is to install "stress strips" in the existing gloves, which minimizes the needed travel distance to control a tool and allows that movement be sensed where glove movement is easiest. Studies also identified a potential need for audio feedback. Future work will explore the installation of audio sensors in the glove and the human factors of feedback in using hand power tools.

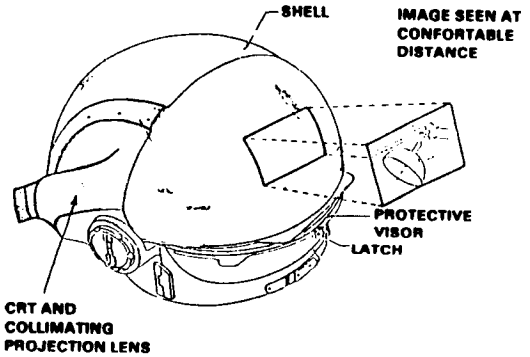
Generic Work Station - The generic work station concept is for a device that an EVA crewman can take to a remote site, which may be either prepared or unprepared, and set up as a positioning and support aid for EVA activities. Major program elements include looking at waist and foot restraints, single or multiple structural attach points, and to trade-off the reach and positioning of the mechanism against the overall rigidity and restraint capability. Results to date have shown that a distributed load single attach point gives better positioning capability and portability, and can give sufficient restraint capability. A four degree of freedom "arm" will be tested in neutral buoyancy facilities to work out final design and human factors requirements during future program activities.

TECHNICAL CONTACT: Manuel Rodriguez, JSC (713) 483-5536

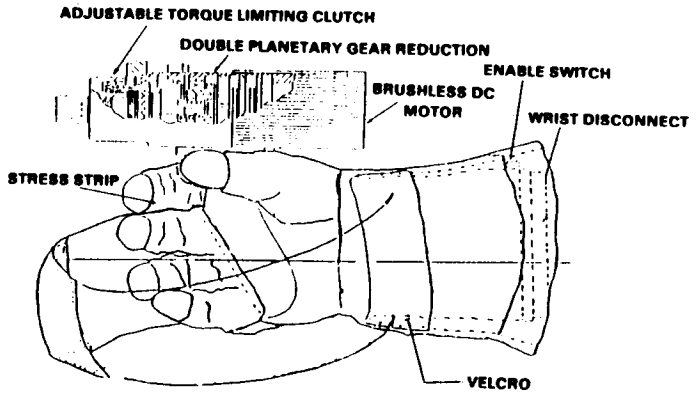
EVA PERFORMANCE AIDS

HELMET MOUNTED DISPLAY

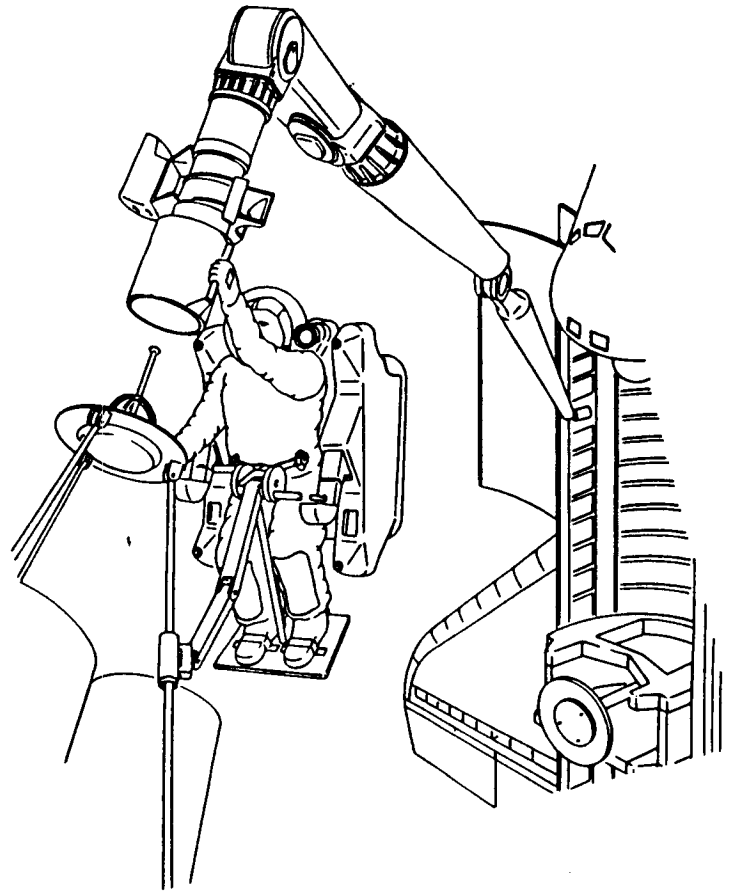
- PROVIDES UNENCUMBERING, REAL TIME EVA SYSTEMS MANAGEMENT
- PROVIDES REAL TIME AUDIO, VISUAL DATA UPLINK
- PROVIDES DISPLAY OF PREPROGRAMMED DATA



POWER ASSISTED GLOVE END EFFECTOR



GENERIC WORK STATION



Sensor Technology

The objective of the Sensor Technology Program is to provide the necessary technology to advance and enable the active and passive sensing of terrestrial, planetary, and galactic phenomena through the exploitation of microwave, laser and solid state technology.

The program is balanced among four major research and development (R&D) discipline areas as follows: detector R&D, laser and tunable sources R&D, submillimeter wave R&D, and sensor support R&D. Ongoing work consists of research and development of detector arrays with maximums in sensitivity from the far infra-red to the upper reaches of the submillimeter portion of the electromagnetic spectrum (250 micrometers in wavelength). Also included are research tasks in the spectral (200 electron volts resolution) and spatial imaging of x- and gamma-rays for astronomical missions.

Heterodyne spectroscopy has been determined to be a very viable method for sensing in the submillimeter band (300 to 3,000 GHz). Component research is focused on local sources such as quantum well devices, superconducting-insulating-superconducting mixers with a 600 GHz bandwidth, and quasi-optic components. Laser technology includes research on semiconductor arrays for pumping, doubling crystals for frequency shifting and solid state materials work on amplifiers and phase shifters.

PROGRAM MANAGER: Dr. Martin Sokoloski
NASA/OAST/RC
Washington, DC 20546
(202) 453-2748

CCD Enhanced UV and X-Ray Response

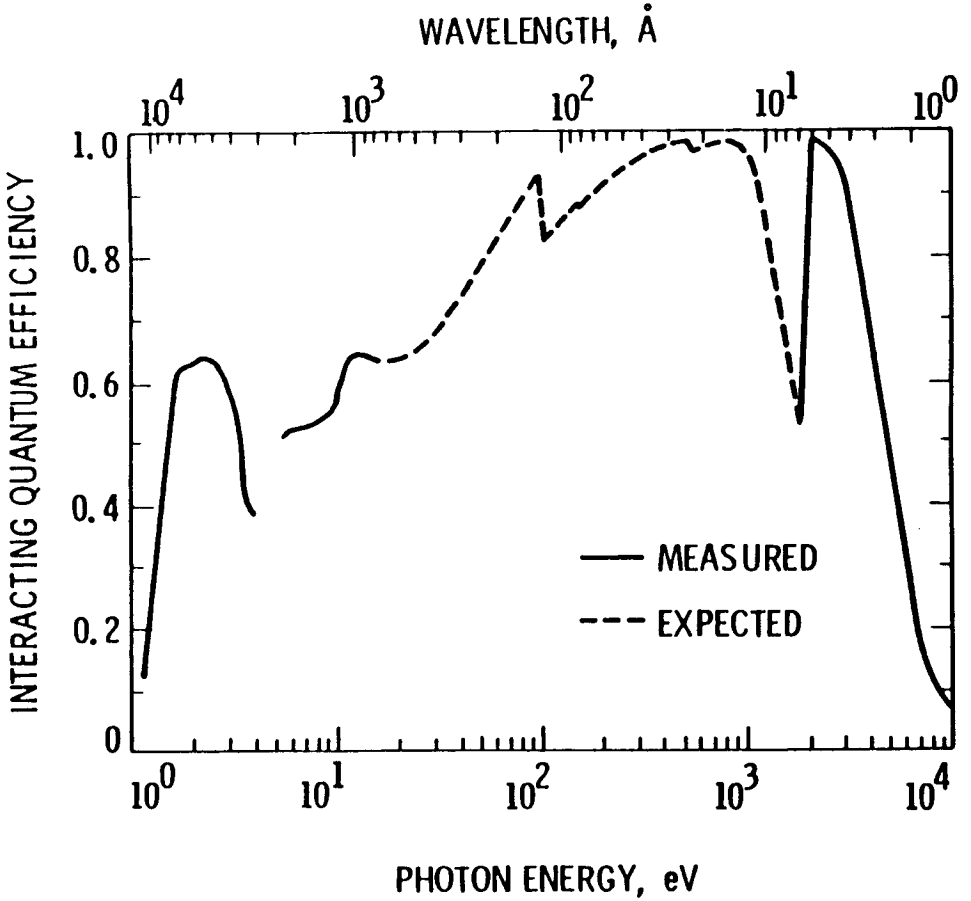
Significant progress has been made in expansion and enhancement of charged coupled device (CCD) spectral response into the UV and X-ray range. This has been achieved through analytical study and experimentation leading to a better understanding of back surface hole accumulation and charging effects as well as practical and controllable methods for effecting improved charge collection, quantum efficiency (QE), and stable operation. In the past several years there has been a surge of interest in the areas of UV, XUV, and X-ray instruments for astronomy. This interest, coupled with an unexpected short wavelength instability of the quantum efficiency of the thinned backside illuminated 800 x 800 Texas Instruments three-phase CCD used by the Wide Field/Planetary Camera (WF/PC) for the Space Telescope, has stimulated a detailed investigation of the short wavelength response (1 Å < <5000 Å) and performance potential of the CCD as a detector for this spectral region. It has been demonstrated at JPL that uncoated devices are useful detectors with potential to achieve very high quantum efficiencies over the entire spectral range, 1 to 11,000 Å (i.e., from the soft X-ray to the near IR).

The phenomenon of QE "pinning", a condition which results from backside charging wherein all photo-generated electrons are collected in the CCD potential wells, is important to this technology and was found to be controllable. Three techniques of providing backside charge to the CCD were found to optimally charge the sensor to achieve QE-pinning. The three methods are: (1) photo-emission charging using a UV lamp flooding; (2) charge tunneling by gas (NO) "soak"; and (3) corona charging. Experimental data obtained using these techniques is shown to be consistent with theoretical understanding (see opposite figure).

This new understanding of CCDs will provide a basis for design of many new instruments in the extended spectrum.

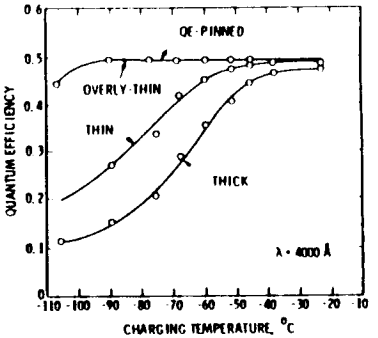
TECHNICAL CONTACT: S. A. Collins, JPL (818) 354-7393

CCD ENHANCED UV & X-RAY RESPONSE



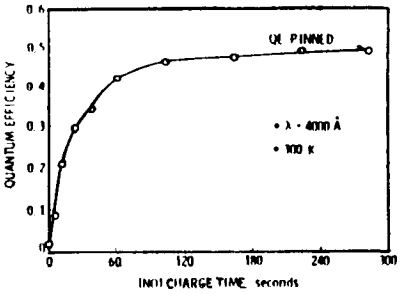
BY BACKSIDE UV FLOODING

QE vs CHARGING TEMP



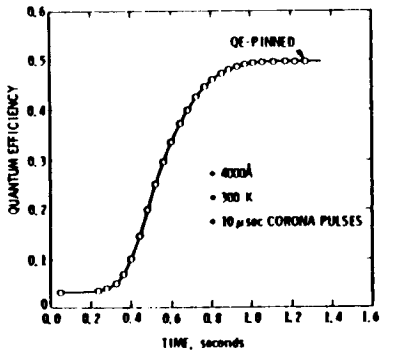
BY GAS (NO) CHARGE TUNNELING

QE vs GAS CHARGING TIME



BY BACKSIDE CORONA CHARGING

QE vs CHARGING TIME



Imaging X-Ray Spectrometer

The Imaging X-Ray Spectrometer is a solid-state silicon detector using "deep diodes" formed by thermomigration of aluminum through the wafer. Thermomigration is a method in which temperature gradient diffusion is used to drive aluminum posts through a silicon substrate with a lateral spread of a few percent (less than 5%) of the substrate thickness. The first such x-ray detectors were designed, fabricated, and tested at the Goddard Space Flight Center.

The detector array is unique because it offers both good energy and spatial resolution for the analysis of x-rays in the 1 to 30 keV range. Because the aluminum posts go completely through the detection substrate, the complete thickness of the wafer can be depleted, leading to high quantum efficiencies for x-rays in the 1 to 10 keV range. The quantum efficiency is a function of the silicon thickness; a quantum efficiency of 98% has been achieved at 10 keV.

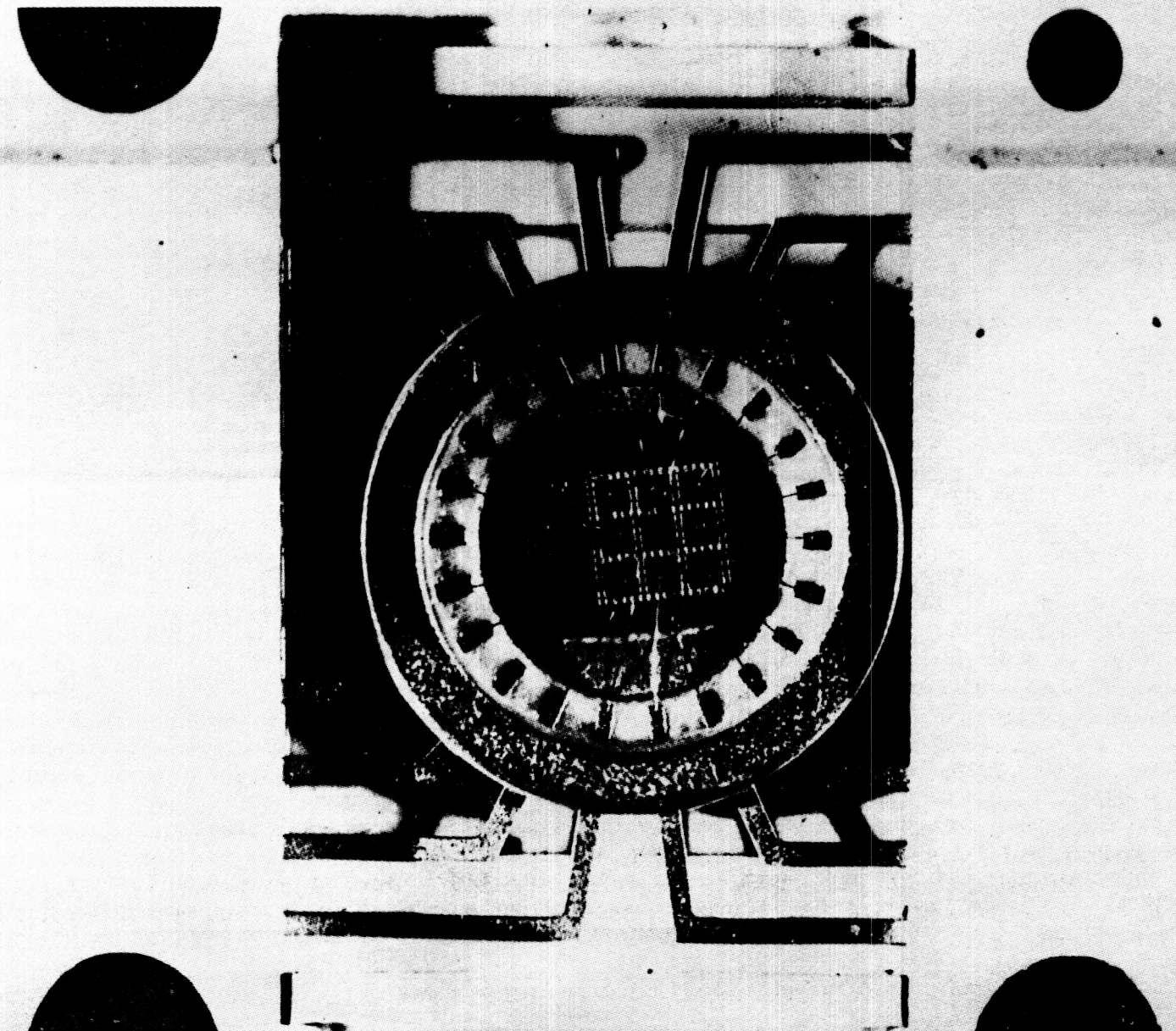
The thickness of the wafers to be used is only limited by the ability to drive posts, since depletion voltages are now independent of substrate thickness. To date, good posts have been driven through 1300 micrometer wafers. Spatial resolution is attained by forming a grid structure surrounding individual thermomigrated aluminum posts. In the middle of each pixel is a post which forms the electron collection terminal for the individual pixel. An array of greater than 100 pixels, 1 mm^2 per pixel, is planned for the Advanced X-Ray Astrophysics Facility (AXAF) mission.

The critical parameter of interest is the noise level of the detector system. This noise level is measured by utilizing a Pulse Height Analyzer (PHA) spectrum of the 5.9 keV Mn alpha line. The Full Width Half Maximum (FWHM) of the peak (in ev's) is considered the noise level for the detector system. Total noise has dropped from 2.25 keV in the early stages of research to a present value of about 250 ev. Of this 250 ev, about 190 ev is due to the detector while about 150 ev is due to the electronics. Improvements in on-chip integration of electronics and detector arrays should reduce system noise levels. Process and material changes are expected to further reduce the noise level of the detector. On-chip integration of the electronics is being performed by computer-aided design (CAD) of amplifier systems in negative metal oxide semiconductor (NMOS) silicon gate technology to attack the electronics noise level.

Another important factor is the available pixel size. Detector development using 7000 ohm-cm material has increased the pixel size so it is no longer a problem. A 700 micron pixel size is readily obtained at voltages of 100 volts. Research is continuing to further reduce system noise levels and provide maximum integration.

TECHNICAL CONTACT: George Alcorn, GSFC (301) 344-5374

PACKAGED X-RAY CHIP FOR IMAGING X-RAY SPECTROMETER



PACKAGED X-RAY CHIP

Advanced Detectors for Space Applications

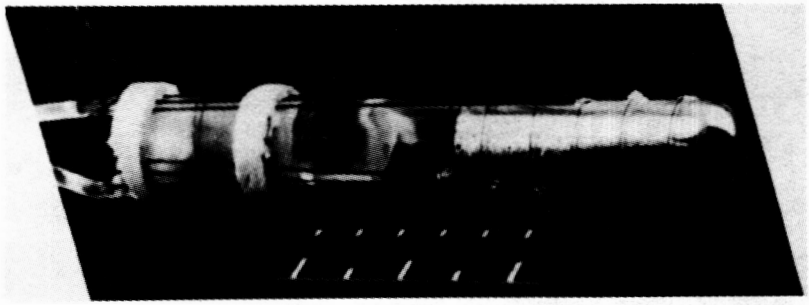
The objective of this program is to improve detector technology for space-based earth sciences and remote sensing studies. The approach will be to develop new, more stable and reliable solid-state materials and devices for visible and IR sensing experiments. Current devices suffer from lack of reliability and stability, leading to lifetimes that are inadequate for long term space missions. Also, in certain regions of the spectrum such as VIS and near IR, sensing devices lack the sensitivity required for most practical space platform experiments. This program addresses these issues through the development of a new detector material (HgZnTe), a new shortwave IR detector (Ge APD), and theoretical studies to develop materials and devices with enhanced properties.

Recent experimental and theoretical developments indicate that HgZnTe can be grown with a wide compositional variation in the material constituents and that it is more resistant to damage than HgCdTe. This program addresses, on a cooperative basis with DOD, the crystal growth, material characterization, and device fabrication of HgZnTe. A development program in Ge APD devices is being pursued for near-IR laser ranging and communications. The proposed p+/n structure will be faster and more efficient. Additionally, the program will enable a technology base where none currently exists in this country (all Ge APDs come from Japan). Finally, a program to identify new III-V materials and processes to further increase the sensitivity and wavelength coverage of advanced detectors for space applications will be undertaken. The initial effort will concentrate on the electronic properties of group IIIA and VA elements in combination with Bi in ternary and quaternary compounds.

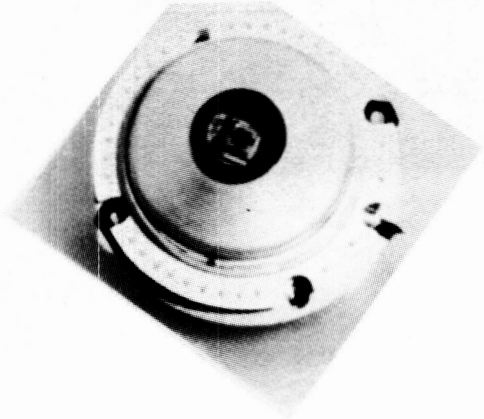
TECHNICAL CONTACT: William E. Miller, LaRC (804) 865-3535

ADVANCED EARTH SCIENCES DETECTOR RESEARCH

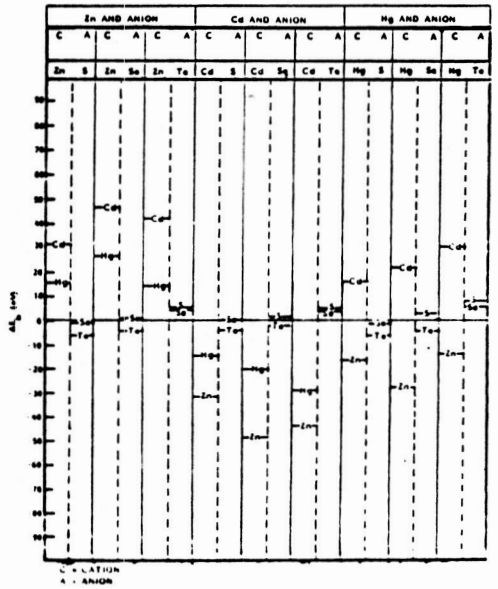
HgZnTe TECHNOLOGY DEVELOPMENT



SOLID STATE DETECTOR DEVELOPMENT



BONDING ENERGY STUDIES



BENEFITS

- HgZnTe TECHNOLOGY PROGRAM
  - — Stronger and more structurally robust than HgCdTe
  - — Demonstrated single crystal growth
  - — Increased Stability, fewer Crystal defects
  - — Replacement for HgCdTe, same wavelength coverage
- III-V MATERIALS STUDY
  - — Theoretical study of structural & Electro-Optical properties of ternary & quaternary compounds containing Bismuth
- Ge APD STRUCTURES
  - — P+/N device for increased gain and specified for 1.0 to 1.5 um range

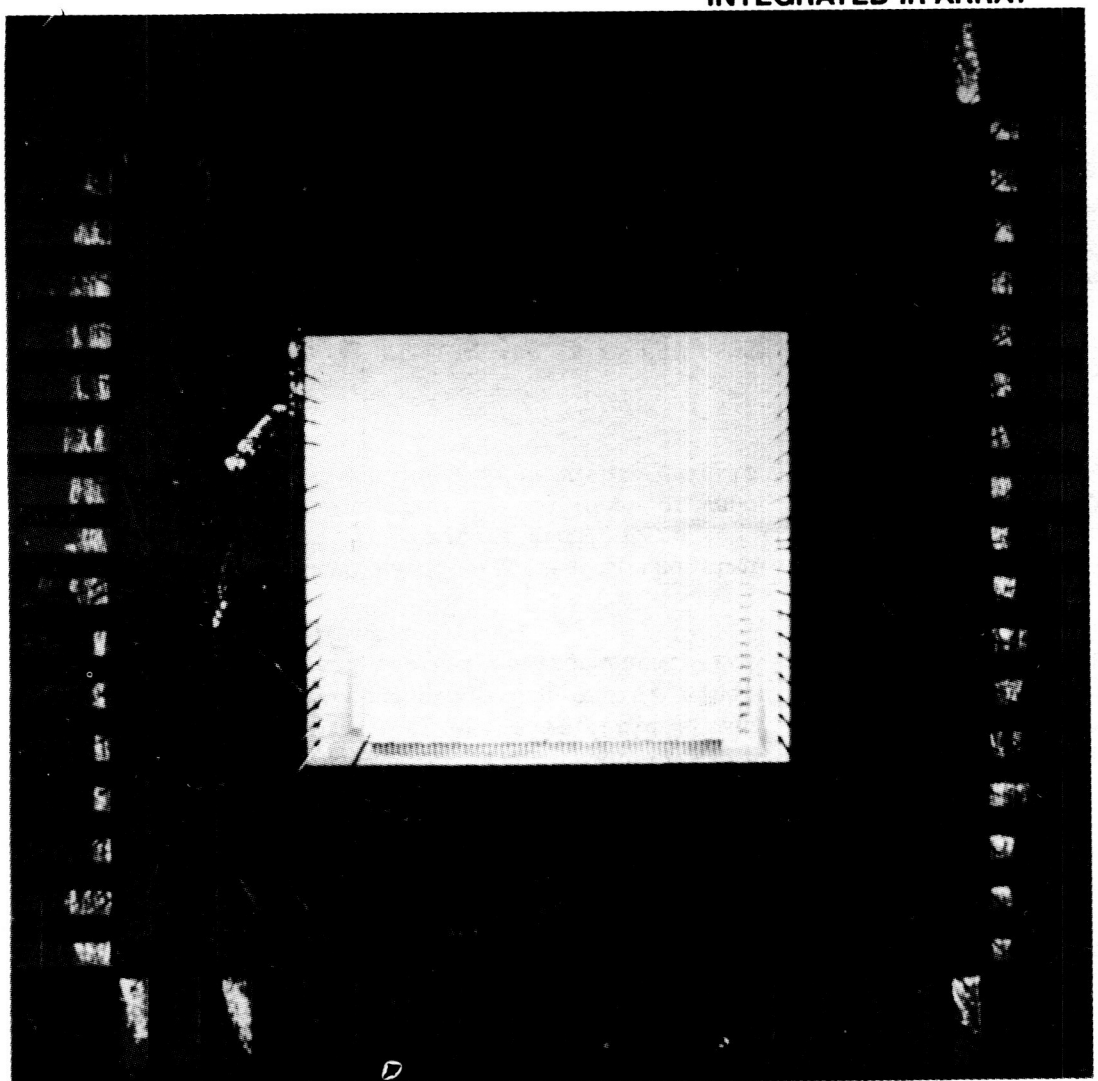
Development of an Antimony-Doped Silicon Integrated IR Array

The spectral response of integrated IR array technology has been extended out to 30 microns with the development of an antimony-doped silicon (Si:Sb) multiplexed array. Under a subcontract to Santa Barbara Research Center, the Hughes Carlsbad Advanced Technology Center has produced hybrid Si:Sb arrays of 58 x 62 pixels. Each pixel is nominally 75 micron square, and the array frontal area is 100% optically active. The array is read out with the state-of-the-art CRC 228 direct readout (DRO) multiplexer. This device, shown on the opposite figure, offers significant advantages for low-background space astronomy applications. Its readout noise is in the 50 - 100 rms electrons range, an order of magnitude lower than that of charge-coupled device (CCD) multiplexers. It also allows pixels to be interrogated while they are integrating charge without penalty (nondestructive read), and pixels or groups of pixels can be read out in an arbitrary sequence (random access). These new capabilities should be extremely valuable in space, allowing (a) nuclear particle hits to be discriminated, and (b) the imaging of faint objects in close proximity to bright ones.

The arrays will be characterized at ARC in FY 86 under low-background conditions representative of the Space Infrared Telescope Facility (SIRTF). The results will be incorporated into the concept definition of the SIRTF Infrared Array Camera (IRAC), which has selected this Si:Sb DRO array for its baseline Band III focal plane. It will also be evaluated for potential application in the SIRTF Infrared Spectrometer (IRS). For future astronomical applications such as the Large Deployable Reflector (LDR), this project has value both as an example prototype multiplexer (applicable to other detector materials) and as a 30 micron sensor system.

TECHNICAL CONTACT: Craig R. McCreight, ARC (415) 694-6549

DEVELOPMENT OF ANTIMONY-DOPED SILICON INTEGRATED IR ARRAY



HYBRID Si:Sb ARRAY, WITH HUGHES CRC 228 MULTIPLEXER

TECHNICAL FEATURES:

- FIRST INTEGRATED ARRAY SENSITIVE OUT TO 30 μM (IMAGING OF NEW SPECTRAL FEATURES)
- ADVANCED READOUT
  - -READ NOISE ~ 10x LOWER THAN CCDs
  - -RANDOM ACCESS
  - -NONDESTRUCTIVE READ
- LARGE FORMAT (58 X 62)

APPLICABILITY - SPACE ASTRONOMY

- ADOPTED AS BASELINE FOR SIRTF INFRARED ARRAY CAMERA
- POSSIBLE USE IN SIRTF IR SPECTROMETER
- POTENTIAL TECHNOLOGY FOR LDR 30 μM IMAGING

Dewar Simulator

A mechanical simulator for testing Dewar supports has been built for ARC by Lockheed Missiles and Space Division. The simulator shown on the opposite figure consists of two plates connected by the supports to be tested. The upper plate simulates the cryogen tank. It can be loaded to simulate different conditions such as launch, ground hold, and orbital operation. The lower plate simulates the outer shell of the Dewar. The support mounting points can be moved radially to simulate thermal contractions of the tank and outer shell. Each mounting point can be moved independently, which allows thermal gradients to be simulated. Variable side loads can also be applied to the supports to simulate the weight of vapor cooled shields.

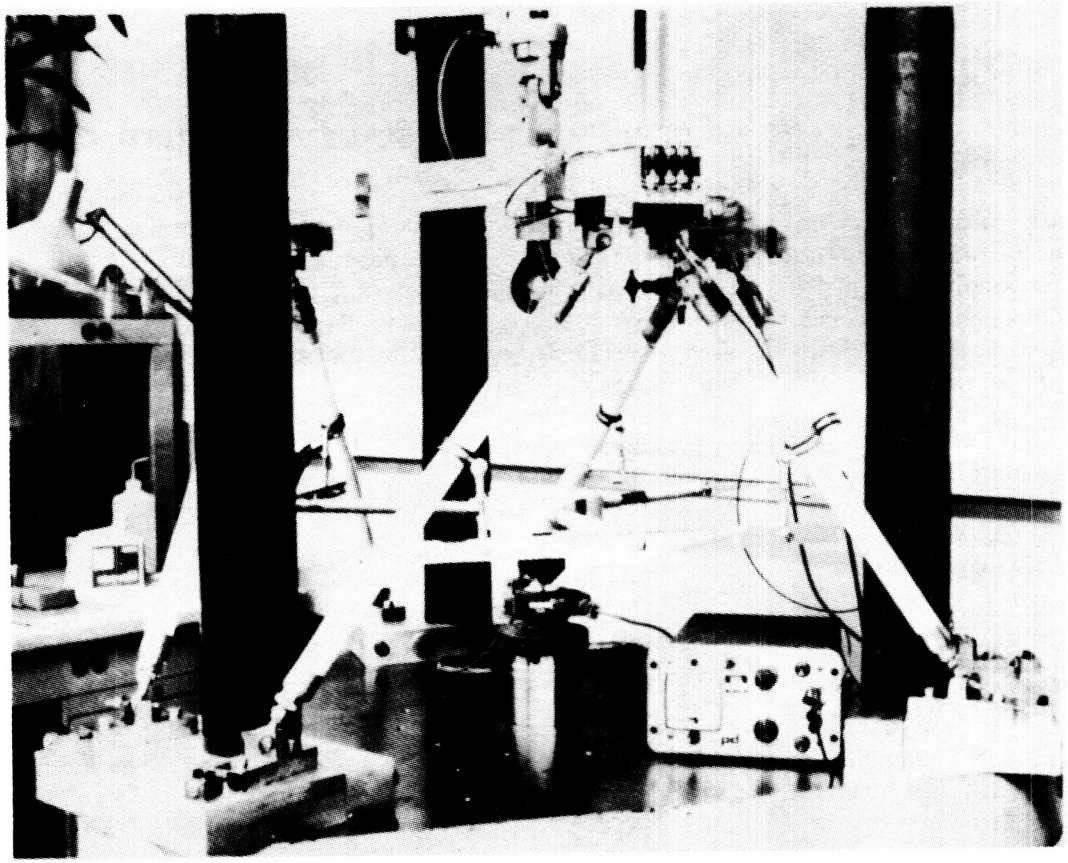
The Passive Orbital Disconnect Strut (PODS III) has been tested in the simulator. These struts are an advanced type of Dewar support system. They are a variable strength, variable thermal conductance device designed for high strength during launch and low conductance in orbit. The simulator was built to test a system of six PODS in the expected launch, ground hold and orbital environments. Previously, only a single PODS had been tested. Six PODS are required for a statically determinant system.

The following tests have been performed in the simulator: 1) axial load configuration to the launch configuration; 2) simulated outer shell temperature gradient to see if such a gradient would short the struts; 3) side loads required to short the struts, i.e., simulate the loads of vapor cooled shields; and 4) modal vibration of the struts. The results of these tests were in good agreement with predictions. As a result of these tests, the PODS are considered to be space flight qualified.

TECHNICAL CONTACT: Peter Kittel, ARC (415) 694-6525

DEWAR SIMULATOR

TEST BED FOR PASSIVE ORBITAL DISCONNECT STRUTS (PODS)



SIMULATES

- TANK COOL DOWN
- OUTER SHELL COOL DOWN
- OUTER SHELL TEMPERATURE GRADIENTS
- LAUNCH LOADS
- GROUND HOLD LOADS
- ORBITAL LOADS
- VAPOR COOLED SHIELD LOADS

TESTS

- SHORTING LOADS
- MODAL VIBRATIONS

Excimer Lasers for Remote Sensing

A program to develop advanced sensors based on high power, efficient, ultraviolet excimer lasers for eventual space applications is being successfully implemented for several timely ground-based demonstrations. The Raman shifted excimer LIDAR concept was chosen by the Office of Space Science and Applications (OSSA) to be used for remote montioring of stratospheric ozone from a ground-based LIDAR facility being constructed at JPL. The ground-based high power excimer LIDAR will eventually provide NASA with measurements of ozone, water vapor, temperature and density profiles in the atmosphere at a lower cost and with greater precision and accuracy than is now being obtained using aircraft, balloon and rocket soundings for these measurements (see opposite figure).

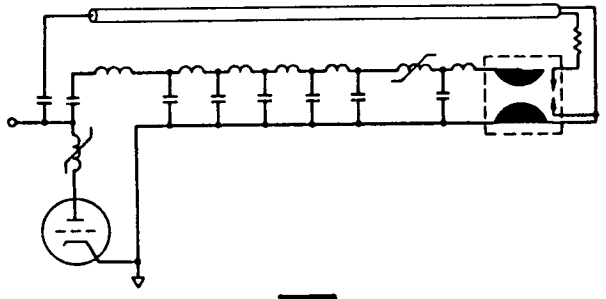
The advanced technology for the high power XeCl excimer laser and Raman wavelength converter is being developed by the OAST program for this LIDAR application and should be operational late in FY 86. A second excimer LIDAR field demonstration for an incoherent Doppler wind measurement is planned for early FY 86. This LIDAR concept is based on the successful demonstration of single longitudinal mode ultra-narrow bandwidth operation of a XeCl oscillator-amplifier system developed in the OAST sensor program. This wind measurement is to be made in collaboration with members of the University College of London, who are supplying the narrow bandwidth filter/detector necessary to measure the small Doppler shift. JPL has already successfully demonstrated several improved laser surgical procedures using the OAST prototype excimer lasers in a NASA funded program with Cedars-Sinai Medical Center for biomedical applicatons.

The patented development of reliable, efficient and compact magnetically switched pulsed discharge circuitry for the excimer laser demonstrated in the OAST program makes an excimer laser based LIDAR a strong candidate for a space-based sensor for Earth Observing System (EOS) and it's Laser Atmospheric Sounder and Altimeter (LASA) platform. To meet the program needs for EOS, JPL will continue to emphasize LIDAR field demonstrations using current excimer technology to measure atmospheric parameters and species. In addition, the development of improved laser components to meet the stringent requirements for long-term laser sensor operation from a free flyer in space will be continued.

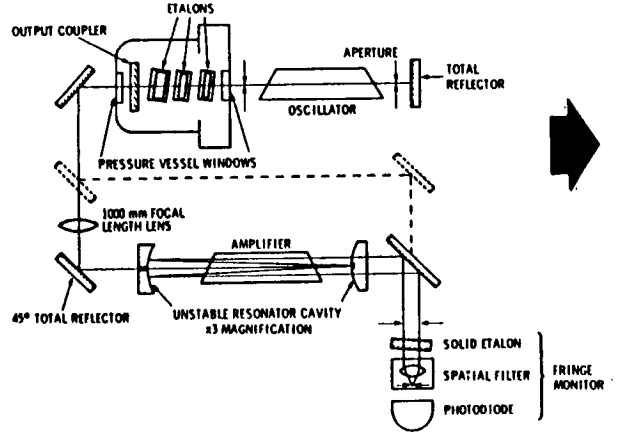
TECHNICAL CONTACT: James Laudenslager, JPL (818) 354-2259

INNOVATIVE LASER SYSTEMS— DEVELOPMENT OF EXCIMER LASERS FOR REMOTE SENSING

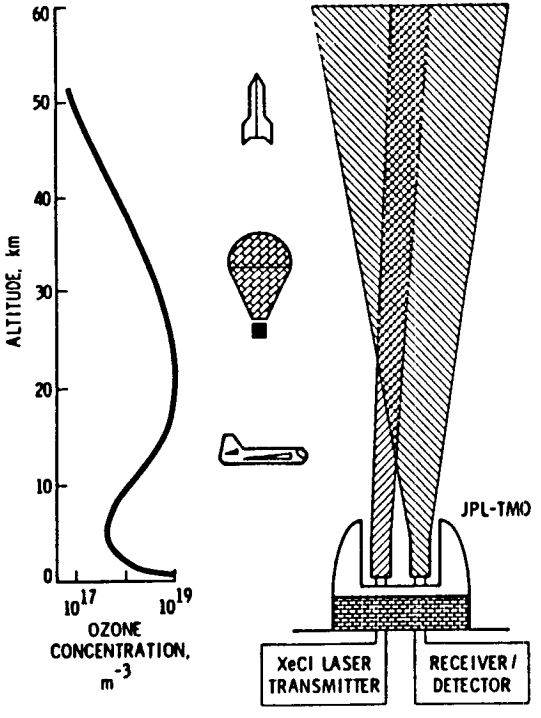
MAGNETIC SWITCH DISCHARGE CIRCUIT



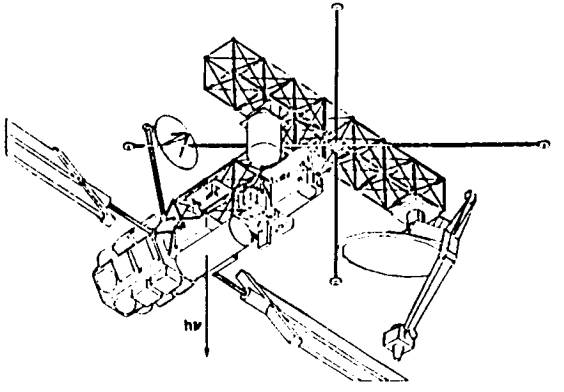
TUNABLE, NARROWBAND XeCl OSCILLATOR/AMPLIFIER WIND SENSOR



GROUND-BASED XeCl LIDAR MEASUREMENT OF STRATOSPHERIC OZONE



Eos PLATFORM



RAMAN SHIFTED XeCl LIDAR FOR Eos/LASA

LABORATORY

FIELD

SPACE

Solid State Laser Transmitter Research

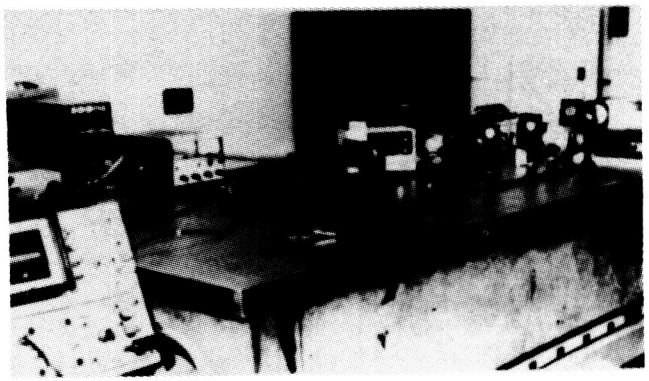
In addition to supporting flight programs, the Langley in-house program includes laser materials characterization and development of laser tuning, line-narrowing and stability control techniques. A specialized Solid State Laser Laboratory has been assembled to support these programs.

To illustrate how regions of interest can be reached with strong, usable transmitter outputs, the titanium doped sapphire absorption/emission spectra is shown below the NASA science spectra on the opposite figure. Two study contracts will examine the material characteristics of titanium doped sapphire ($Ti:Al_2O_3$) as well as determine the elements of oscillator design which affect the energy, stability, and tunability of narrow linewidth transmitters. Another effort addresses the system issues of Solid State Laser Transmitters and examines $Ti:Al_2O_3$ as a candidate source. This study will result in a Transmitter Conceptual Design for use on Space Station related and other free flying platforms, such as EOS.

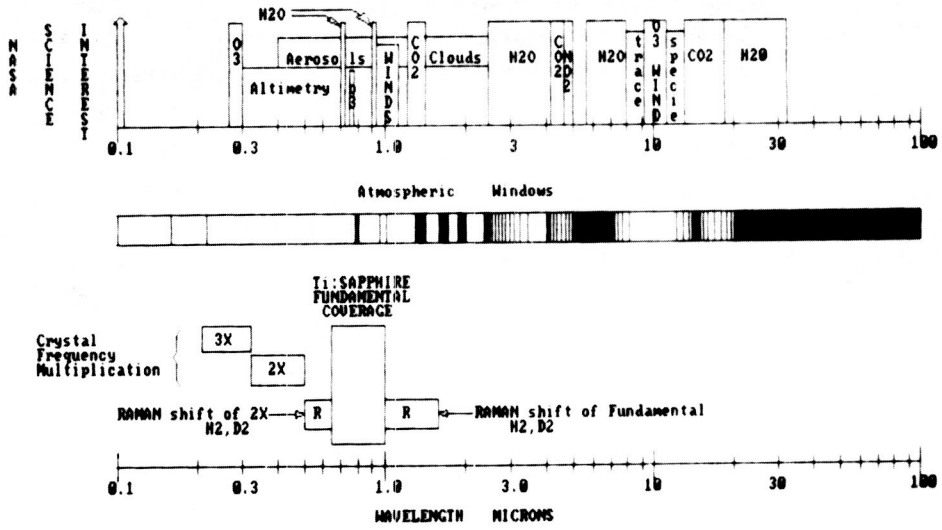
TECHNICAL CONTACT: Art Newcomb, LaRC (804) 865-3761

SOLID STATE LASER TRANSMITTER RESEARCH

LABORATORY Ti:SAPPHIRE LASER BREADBOARD



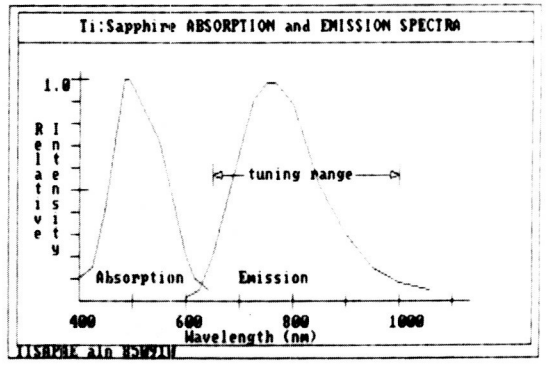
SCIENCE APPLICATIONS OF Ti:SAPPHIRE RANGE



BENEFITS

A SINGLE TUNABLE LASER IN A PROPERLY DESIGNED TRANSMITTER CAN DELIVER THE SCIENCE OF MULTIPLE INSTRUMENTS USING FIXED WAVELEGNTHS. THE LASER MUST:

- **FULFILL REQUIREMENTS OF SPACECRAFT CONSTRAINTS**
  - **—HIGH OUTPUT ENERGY, 1 TO 2 JOULES**
  - **—HIGH EFFICIENCY > 2%**
  - **—LONG LIFETIME TO 1 BILLION SHOTS**
- **PROVIDE SPECTRAL TUNING RANGE**
- **PROVIDE SPECTRAL PURITY AND STABILITY FOR DIAL APPLICATIONS**



Laser Diode Array Technology

The object of this program is to define, develop, and evaluate advanced semiconductor laser diode pump arrays for application in advanced all-solid-state Laser LIDAR systems for improved measurements of atmospheric properties from space platforms. One of the key recommendations of a topical meeting held in May 1985 on Tunable Solid State Lasers, and a NASA sponsored workshop conducted in the fall of 1984 on Tunable Solid State Lasers for remote sensing, was the development of reliable, long lifetime diode pump arrays for solid state laser systems.

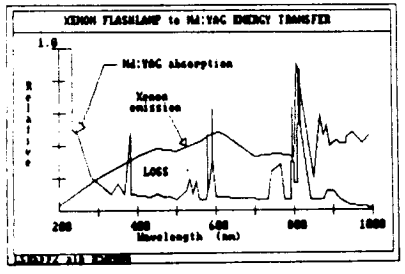
Key to the use of laser remote sensing in space is the development of all-solid-state laser and LIDAR systems. Currently, the development and evaluation of advanced solid state laser materials and IR-detector materials and devices is being actively pursued. While these efforts will lead to improved performance of solid state laser and LIDAR systems used in remote sensing, it is absolutely critical that the flash lamp pumps used in these systems be replaced by a more efficient pump source in order that the power consumption restraint imposed by space operation be met. Laser diode arrays offer the only known substitute that can meet this critical requirement for operation in space of advanced Tunable Solid State Lasers and LIDAR systems.

LaRC has been the NASA leader in the support of semiconductor laser diode technology development. In the 1970's, LaRC initiated a program to develop semiconductor laser materials and advanced laser diodes. Program results have been shared with other NASA centers. This effort has resulted in significant accomplishments such as demonstration of a single-mode, CW, CDH-LOC laser of greater than 40 mW, a CW linear diode array of 300 mW, and more recently a small submodule, two dimensional array of 2.0 watts output. Additionally, LaRC continues its support of the development of diode pumped Nd:YAG lasers and amplifiers at Stanford University. This work, which has applications in remote coherent wind velocity measurements, has lead to the invention of the MISER master ocsillator and the demonstration of a diode pumped very narrow linewidth, low power Nd:YAG laser.

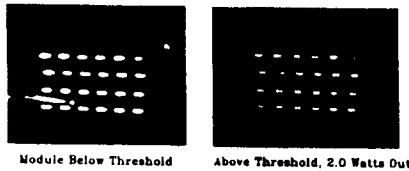
Laser diode arrays, both linear and circular, composed of collections of discrete devices have been available for more than 5 years. The operational characteristics of discrete laser diodes is well established and documented. Two dimensional arrays are presently in the laboratory stage of development. A goal of this program is the development of two dimensional semiconductor laser diode arrays that emit greater than 1,000 watts per square centimeter. One application of these arrays is as pump sources for all-solid-state laser and LIDAR systems operation in space for performing remote atmospheric sensing.

TECHNICAL CONTACT: Carl J. Magee, LaRC (804) 865-3418

LASER DIODE ARRAY TECHNOLOGY

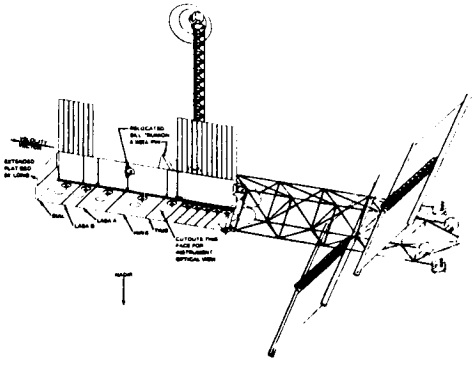


Near-Field Photomicrograph of an Operating Partially Filled Array Submodule

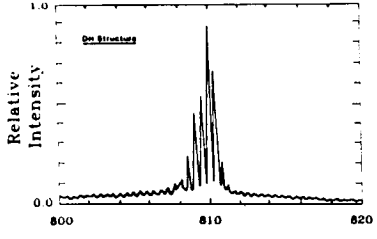


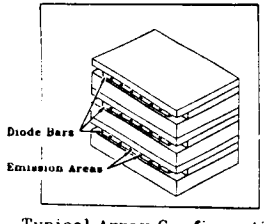
Module Below Threshold

Above Threshold, 2.0 Watts Output



AlGaAs Laser Diode Output Spectrum





Typical Array Configuration

BENEFITS

- **High Efficiency**
- **Long Lifetime**
- **Pump for All Solid State Lidar Systems**
- **Sensors for Proximity Operations**
- **Sources for Space Communications**

Catalyst Studies for CO_2 LIDAR

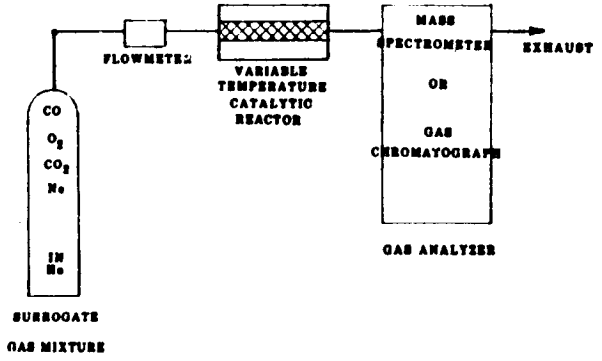
Development of catalysts for the recombination of CO and O_2 to CO_2 is vital for long-life, closed-cycle operation of CO_2 lasers for Doppler LIDAR measurements from space platforms such as EOS. Low temperature ($<100^{\circ}C$) catalyst operation is desirable to allow heating by the laser medium without additional energy expenditure. The feasibility of such operation has been demonstrated in a ~1 joule/pulse, 10 p.p.s. CO_2 laser operating closed-cycle with an external Pt/SnO_2 catalyst at $100^{\circ}C$.

Research is now being performed in a laboratory reactor to increase catalyst efficiency (to minimize catalyst weight and operating temperature) and also to allow operation of the catalyst with rare-isotope CO_2 which yields enhanced atmospheric transmission and aerosol scattering. A CO pretreatment technique has been developed which essentially doubles the catalyst efficiency of Pt/SnO_2. The pretreated catalyst has been tested for 12,000 minutes (equivalent to 7×10^6 shots in a 10 p.p.s. laser) without significant loss of efficiency. It is noteworthy that efficiency of ~100% at $75^{\circ}C$ has been achieved in other tests with sufficient catalyst surface area. In addition, a surface preparation technique has been developed which allows operation of common-isotope Pt/SnO_2 with rare-isotope CO_2 with no deleterious isotope exchange. Further enhancement of catalyst efficiency is in progress, and long term tests involving both common and rare isotope CO_2 are in preparation.

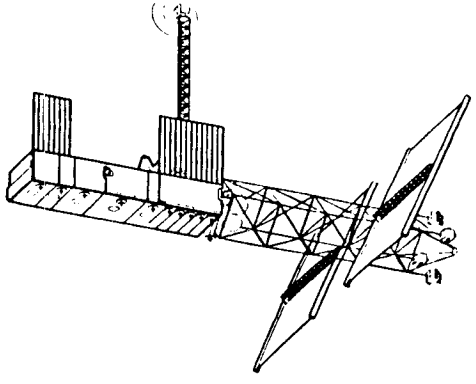
TECHNICAL CONTACT: David R. Schryer, LaRC (804) 865-2818

CATALYST STUDIES FOR CO_2 LIDAR

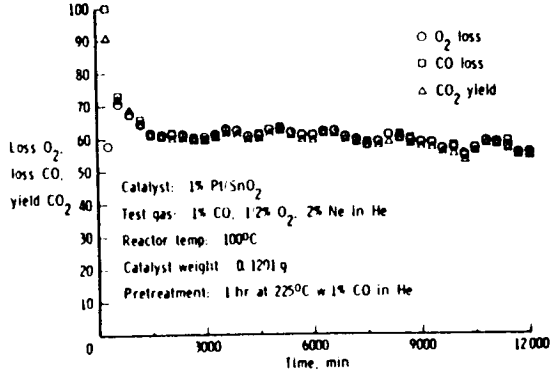
APPARATUS FOR CATALYST RESEARCH USING SURROGATE GAS MIXTURES



EOS PLATFORM FOR CO_2 LIDAR



LONG DURATION TEST OF CO OXIDATION ON Pt/SnO_2



BENEFITS

LOW TEMPERATURE Pt/SnO_2 CATALYST
VITAL FOR LONG-LIFE SPACE-BASED CO2 DOPPLER LIDAR

RARE ISOTOPE CO2 OPERATION
INCREASES ATMOSPHERIC TRANSMISSION

SPIN-OFFS TO KEY DOD MISSIONS

UNIQUE LaRC CATALYST RESULTS
TRANSMITTED TO U.S. INDUSTRY

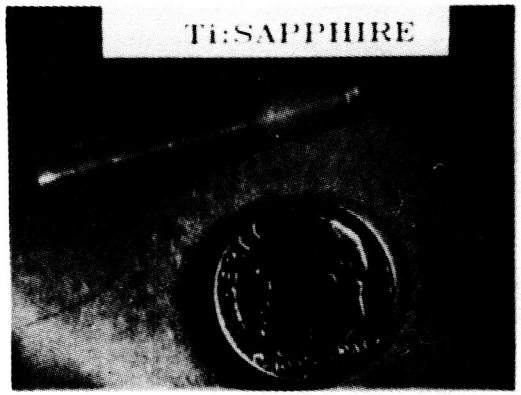
Tunable Solid State Laser Materials

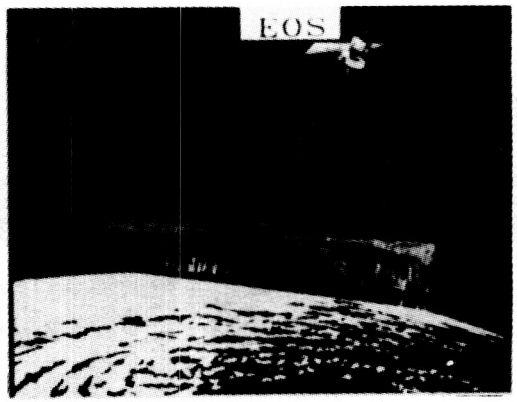
Active remote sensing using LIDAR/DIAL techniques from spacecraft platforms such as the EOS requires high efficiency, stable, and long lifetime laser systems. Recent investigations into tunable solid state lasers have identified materials capable of being tuned over a broad spectral region. For example, alexandrite can lase from 700 nanometers to 800 nanometers and titanium doped sapphire has been shown to be tunable over an even broader wavelength range, from 660 nanometers to beyond 980 nanometers. The laser materials found to date are tunable primarily in the visible to the near IR spectral region. Tunable lasers based on dyes also exist in this regime (up to 1 micron). A few solid state materials have been identified that are capable of tunable lasing beyond 1 micron but will not meet the stringent requirements of a spaceborne laser system.

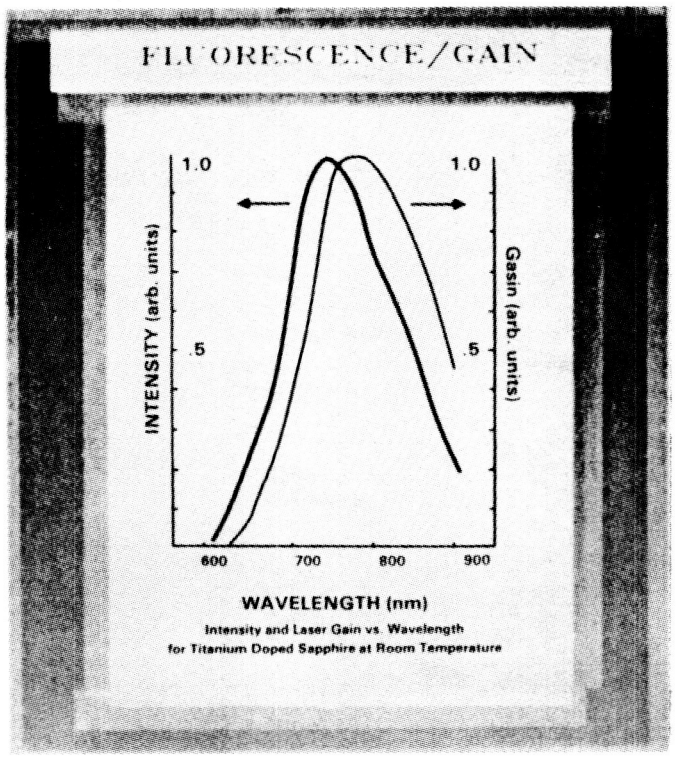
A rapid survey of potential laser ions and materials can be made by measuring absorption and fluorescence characteristics (shown on opposite page). The results of these measurements yield information directly related to practical laser parameters. For example, materials which exhibit broad fluorescence emission will also be capable of tunable Laser operation over a broad wavelength range. An organized survey of candidate ion/host combinations, with emphasis on identifying materials capable of tunable lasing beyond 1 micron, will result in a catalog of laser materials useful to scientists desiring DIAL or Lidar measurements of atmospheric species such as ammonia and carbon monoxide.

TECHNICAL CONTACT: Dr. Charles E. Byvik, LaRC (804) 865-3761

TUNABLE SOLID STATE LASER MATERIALS







BENEFITS

- Sensing of previously unmeasurable atmospheric species (wavelengths >1 um)
- Develop Catalog of available tunable Lasers for DIAL/Doppler
- Enhanced Laser operating characteristics (efficiency, power, stability)

Extended InAs/GaAs Strained-Layer Superlattices

JPL's research on advancing Molecular Beam Epitaxy (MBE) techniques resulted in the first successful growths of extended strained-layer superlattices. Structures consisting of alternating GaAs and InAs layers of 10 to 100 angstroms each were grown to total thicknesses of 1 to 3 micron. The achievement of high crystalline quality over such extended thicknesses (see opposite photograph) is a major milestone toward the practical use of such materials in opto-electronic and high-speed devices. Of particular interest are applications at longer wavelengths (1.5-1.7 micron) for fiber optic systems.

The successful growth of extended strained-layer superlattices requires precise control of growth conditions. A major milestone was achieved this year with JPL's development of Reflection High Energy Electron Diffraction (RHEED) techniques to precisely measure absolute arsenic fluxes. This solved a long-standing problem of MBE techniques for all III-V compounds, improving knowledge of group-V element fluxes by an order of magnitude.

TECHNICAL CONTACT: Joseph Maserjian, JPL (818) 354-3801

CROSS-SECTIONAL TEM OF AN EXTENDED InAs/GaAs STRAINED-LAYER SUPERLATTICE

InAs 3 MONOLAYERS
GaAs 6 MONOLAYERS
InAs 3 MONOLAYERS
GaAs 6 MONOLAYERS
.
.
.

REPEATING LAYERS FOR A TOTAL SUPERLATTICE THICKNESS OF 1.5 μm.

THE BROAD BANDING IS DUE TO STRAIN RELAXATION IN THE THINNED TEM SAMPLE

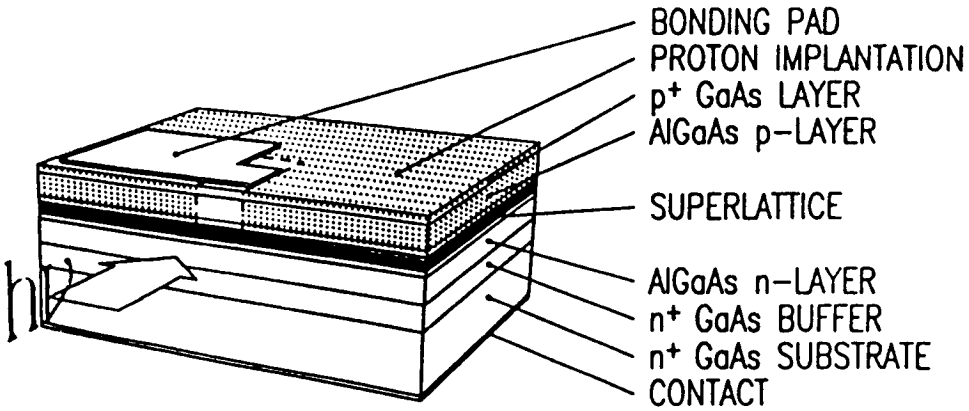
New Superlattice Wavelength-Selective Detector

A new molecular beam epitaxy (MBE) grown AlGaAs/GaAs superlattice p-i-n photodetector has been designed, fabricated and tested through a collaborative effort between JPL and Cal tech (A. Yariv, et al). The device (see opposite figure) is designed to accept incoming light signals along the waveguide formed by the active superlattice layer and the AlGaAs barrier layers. This configuration offers the potential of integrating the detector with lasers and other active devices on the same chip. The device exhibits a large shift in spectral response with applied bias (see figure) due to a theoretically-predicted shift in the quantized excitonic states of the superlattice. This property allows one to voltage-tune the detector to selected wavelengths.

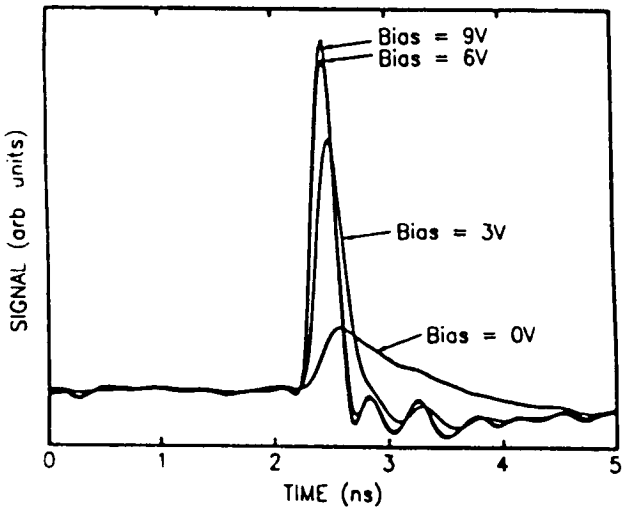
Another feature of the device is its fast response. The temporal response shown in the figure is at present RC-limited to 200 picoseconds at moderate applied bias. The ultimate speed may be much faster, and is limited by field emission of photo carriers out of the quantum wells. The device also has the potential of being reconfigured slightly into an opto-electronic demultiplexer or optical modulator for gigabit optical communication and processing.

TECHNICAL CONTACT: J. Maserjian, JPL (818) 354-3801

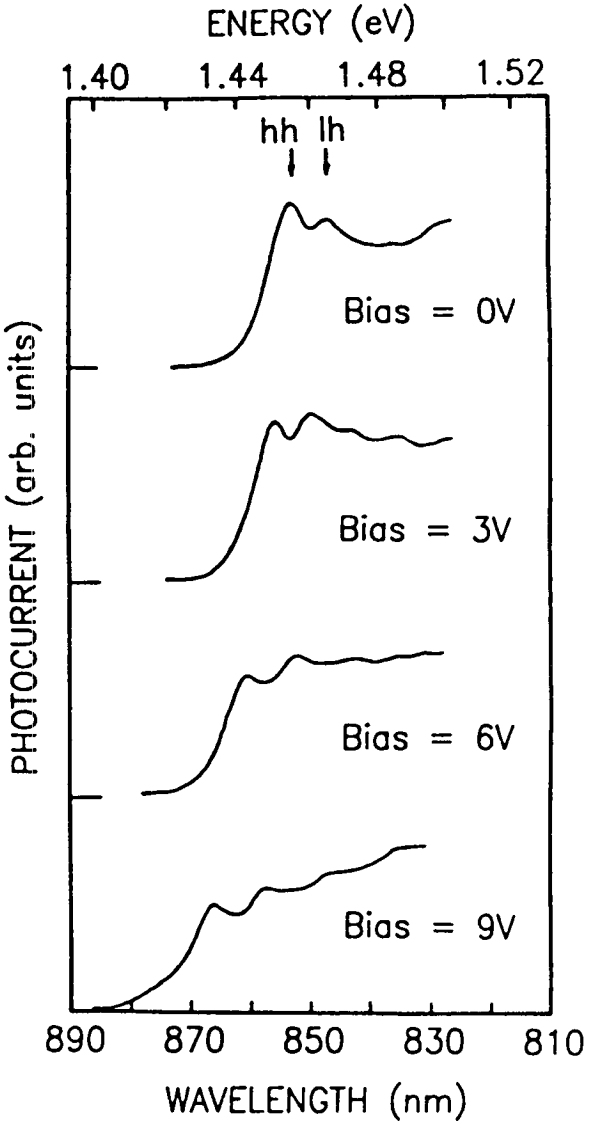
NEW SUPERLATTICE DEVICE
GIGABIT WAVELENGTH–SELECTIVE DETECTOR



Detector structure



Temporal response



Spectral response vs bias

Superconductor-Insulator-Superconductor Mixer Based on Refractory Niobium Nitride

Several future NASA missions such as Large Deployable Reflector (LDR), Earth Observing System (EOS), and Explorer/Orion require an ultra sensitive, low noise receiver in the submillimeter wave frequency range. Superconductor-Insulator-Superconductor (SIS) quasiparticle tunnel junctions hold an immense application potenteial as quantum mixers in such submillimeter wave heterodyne receivers because they require extremely low local oscillator power, have very low noise and very large instantaneous bandwidth.

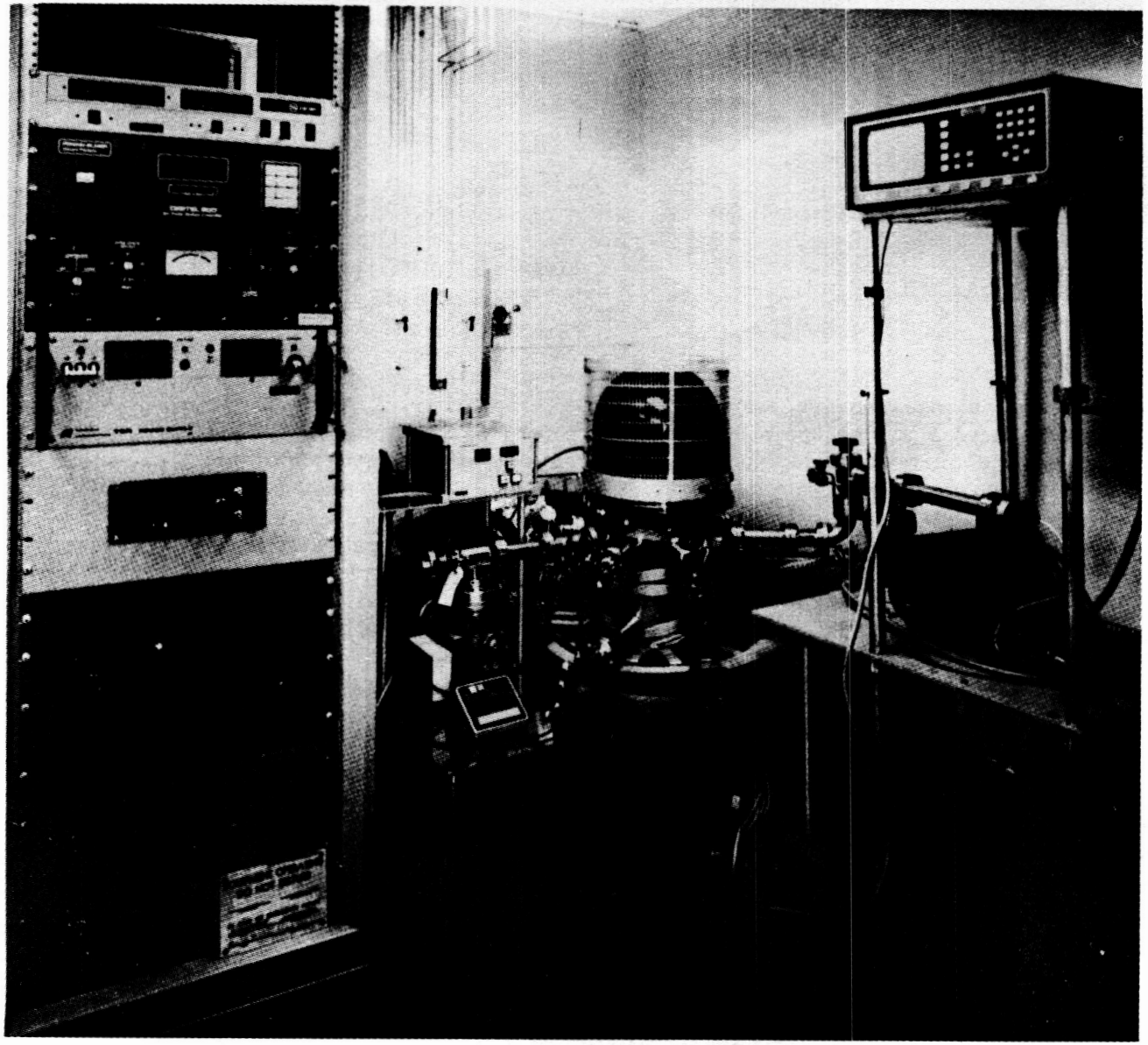
Thin film, submicron area SIS junctions have been fabricated using Pb-based superconducting (T_c) alloys and are currently in use. Such junctions, however, are mechanically soft, exhibit significant degradation on thermal cycling, and the low superconducting gap (≃3 meV) of Pb alloys essentially limits their use to frequency values ≃700 GHz. On the other hand, if the Pb alloys are replaced by a refractory, robust, high T_c material such as niobium nitride (NbN), the junctions are expected to withstand the thermal cycling. Moreover, its high superconducting gap (≃6 meV) also holds a promise of an extended frequency range of application up to ≃1500 GHz.

Refractory NbN, however, has exhibited high T_c only in its metastable NaCl type FCC phase which could be synthesized to date only by deposition at very high substrate temperature, by inclusion of an impurity in the film such as carbon, or by using a single crystal substrate. JPL has demonstrated for the first time that high T_c (16K) stoichiometric NbN films can be deposited on a variety of amorphous as well as crystalline substrates and held at room temperature without an inclusion of any undesirable impurity in the films. The process of d.c. reactive magnetron sputtering (opposite figure) has been adapted for the deposition of the desired phase of NbN and the parameters are optimized through a systematic study of the growth kinetics of such transition metal nitrides. A clear understanding of the reactive gas "consumption-injection" characteristics under magnetron sputtering conditions has thus emerged. The absence of high substrate temperature in the deposition of such NbN films makes them photoresist-compatible and thus highly suitable for the fabrication of SIS junctions.

SIS junctions based on niobium nitride with native oxide as the barrier material and lead as the counter electrode have been fabricated. The current-voltage characteristics exhibit a sharp non-linearity, as desired for a good mixer element. Currently, work is in progress to fabricate an all-hard NbN based SIS junction using native oxide or artificial barrier materials as the insulating layer.

TECHNICAL CONTACT: Satish Khanna, JPL (818) 354-4489

D. C. REACTIVE MAGNETRON SPUTTERING EQUIPMENT



Quantum Well Fundamental Oscillator Development

The objective of this program is to develop a space qualifiable local oscillator source for the submillimeter regime with sufficient output power to drive mixers such as superconductor-insulator-superconductor (SIS) devices and Ge:Ga photoconductors. Quantum well devices with negative resistances have demonstrated response times corresponding to potential operating frequencies as high as 3000 GHz (100 micron). A positive feedback oscillator using these devices has operated at 35 GHz. The use of existing devices as oscillators at higher frequencies is limited by the device and circuit parasitics.

The devices to be used in this program are being produced at Lincoln Laboratories (see lower right, opposite figure). During the past year, the device parasitics have been reduced so that the cutoff frequency is currently about 250 GHz. In the future, the device structure will be adjusted to further increase cutoff frequency. The barrier thickness will be decreased to reduce the negative resistance, the diameter of the device will be reduced to decrease the shunt capacitance, and the depth of the ohmic contact will be shortened to decrease the series resistance. In addition, multiple quantum wells will be grown again, thus reducing the shunt capacitance.

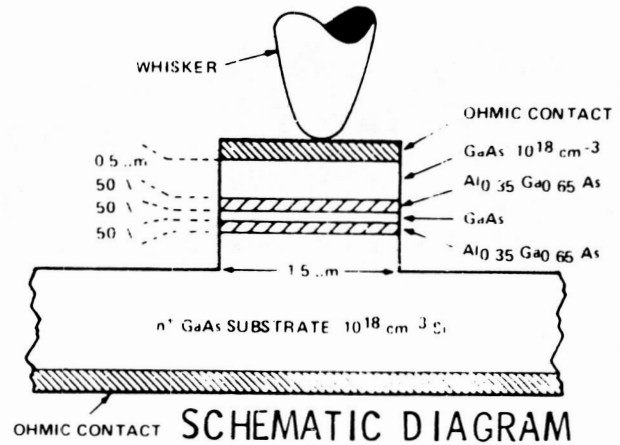
The circuit development is being carried out at JPL. Quasioptical techniques were used to design the circuit to minimize losses in the submillimeter operating regime. To verify the conceptual design, a scaled model of the design operating at 50 GHz was constructed. This will be tested using a Gunn diode as the negative resistance element. The quantum well device will then be tested in the model at 50 GHz. Based on the results from this protytope, higher frequency oscillators will be developed.

TECHNICAL CONTACT: Margaret A. Frerking, JPL (818) 354-4902
Herbert M. Pickett, JPL (818) 354-6861

SUBMILLIMETER LOCAL OSCILLATOR SOURCES

QUANTUM WELL FUNDAMENTAL OSCILLATOR
QUANTUM WELL DEVICE

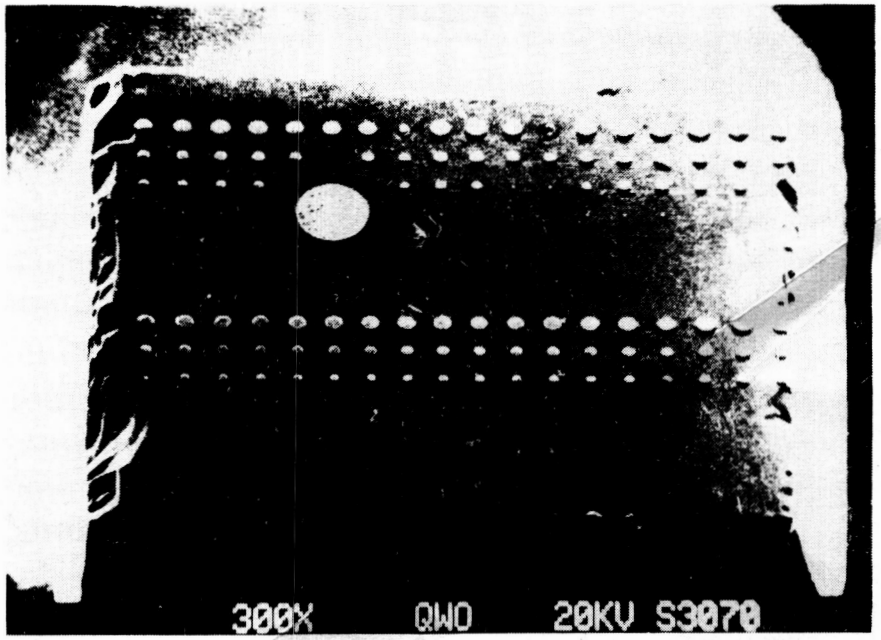
	STATE OF THE ART	DESIGN GOALS
R	-400 Ω	-40 Ω
r	10 Ω	10 Ω
C	70 fF	2.5 fF
f_{max}	35 GHz	3000 GHz
P_{max}	17 μW	17 μW



SCHEMATIC DIAGRAM

MEAN OF ACHIEVING GOALS

ACTION	f_{max} (GHz)	P_{max} (μW)
1. DECREASE BARRIER THICKNESS	100	170
2. REDUCE DEPTH OF MATERIAL USED FOR OHMIC CONTACT	350	170
3. DECREASE DIAMETER TO 1 μm	1000	17
4. USE 3 QUANTUM WELLS	3000	17



SEM OF 3 μ, 5 μ AND 10 μ DEVICES

*U.S. GOVERNMENT PRINTING OFFICE: 1986- 625-014:40001

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-88380		

4. Title and Subtitle	5. Report Date
NASA Information Systems and Human Factors Program Annual Report, 1985	January 1986
	6. Performing Organization Code: RC

7. Author(s)	8. Performing Organization Report No.
Lee B. Holcomb, John D. DiBattista, Melvin D. Montemerlo, Martin Sokoloski, Richard Wasicko, Richard Grumm and Michael McGreevy	
	10. Work Unit No.
9. Performing Organization Name and Address: Information Sciences and Human Factors Division, NASA Office of Aeronautics and Space Technology, Washington, DC 20546	11. Contract or Grant No.
	13. Type of Report and Period Covered: Technical Memorandum
12. Sponsoring Agency Name and Address: National Aeronautics and Space Administration, Washington, DC 20546	14. Sponsoring Agency Code

15. Supplementary Notes

Available from NASA Office of Aeronautics and Space Technology

16. Abstract

This report contains FY 1985 descriptions and accomplishments in seven sections: Automation and Robotics, Computer Sciences, Communications Systems, Controls and Guidance, Data Systems, Human Factors, and Sensor Technology.

17. Key Words (Suggested by Author(s))

Controls, Guidance, Navigation,
Automation, Human Factors, Autonomy,
Computer Science, Data Systems,
Communications, Sensors

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	265	